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AERONAUTICAL PHOTOGRAPHIC EXPERIMENTAL LABORATORY

REPORT NO. NADC AP-6012 15 JULY 1960

PHASE REPORT

INVESTIGATION OF CURRENT TECHNIQUES
OF LOW ALTITUDE PYROTECHNIC FLASH NIGHT
AERIAL RECONNAISSANCE PHOTOGRAPHY.

BUREAU OF NAVAL WEAPONS
TED PROJECT NO. ADC PH-4581

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N O T I C E

A B S T R A C T

This report traces the development of the pyrotechnic flash night photographic system with special emphasis on its application and use in Naval reconnaissance aircraft. The limitations and advantages of the various shutter control modes are briefly discussed from an equipment and performance standpoint. A program of flight test evaluation is outlined wherein the various parameters affecting pyrotechnic flash photography are discussed. A program of mathematical analysis is described which includes the development of a graphical method of presenting the operational limits of the night photographic system as it is affected by airspeed, altitude, cartridge type, fuse delay, ejector orientation, and shutter mode. A correlation is made between flight test data and mathematical data which reveals that the widely accepted value of .09 foot-candle-seconds for minimum scene illumination is unrealistically low and that .135 f.c.s. is a more practical value for the forward corner areas of the field of view of the camera. The off-axis light transmission fall off of the K-47 lens is determined to be the chief contributing cause of this condition. The advantage of upward ejection in the elimination of lens flare is fully substantiated by test photography and its use is recommended for all aircraft installations using the M-112 and M-123 flash cartridges. A method is described for using the operational parameter plots for any film, shutter mode and lens combination having a 41° angular coverage by making a single night photographic flight test. Recommendations are made concerning specific areas where further development of equipment and components is indicated.

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I. INTRODUCTION

Night aerial photography with pyrotechnic illuminants has had a long, rather sporadic, relatively un-co-ordinated period of development. Its progress has been under the influence of many unrelated forces, some stemming from the divergent and ever changing operational requirements of the different military services, while others resulted from technological bottlenecks and periodic "state-of-the-art" breakthroughs. These latter advances have come in many different technical fields including optics, pyrotechnics, film emulsions, camera design and control systems. A brief history of night aerial photography can be found in a report prepared by Chicago Aerial Industries, Inc., (CAI) titled "Night Photography Data", which was issued in June 1956 with later revisions covering the period from 1918 through December 1956. A historical background is considered important in presenting a clear picture of the present "state-of-the-art" of night pyrotechnic photography since the development work accomplished in the past has had a pronounced effect on the design of presently available night photographic equipment. Therefore, a brief summary of the development period from 1918 to the present based in part on the CAI data will follow.

In 1918, the British made several night photographs using a parachute suspended bomb containing 12 lbs. of flashlight powder and a camera that was manually operated in an open shutter, full flash duration exposure. The photographs were not of particularly good quality, being both under exposed and blurred. In 1924 the U. S. Air Force became actively interested in night aerial photography and proceeded to improve the light output of the pyrotechnic illuminants to the point where under exposure was no longer a major problem. Attention was then turned to the image blur problem and considerable improvement was obtained in 1926 through the development of a flash synchronized shutter trip unit using a photo electric cell. Although this mechanism introduced an appreciable delay (about 70 milliseconds) between the initial illuminant burst and the actual opening of the camera shutter and used only about 30% of the available light, it greatly reduced the image blur previously obtained with full flash duration (100 milliseconds) exposures.

During the period from 1926 to 1932, smaller flash bombs were developed having a greater light output per unit of weight although the percentage light utilization was not materially increased until the K-12 camera was developed by the Fairchild Camera & Instrument Co. (FC&IC) in 1932. This camera, when used with a newly developed shutter trip unit, provided a shutter opening lag time of about 46 milliseconds and significantly increased the light utilization permitting higher altitude (approximately 2,000 ft.) operations. However, image blur continued to be a problem primarily because the available light level at 2,000 ft. restricted the use of shutter speeds in excess of 1/25 of a second. In 1933, FC&IC developed a spring motor driven sweep mount which was used experimentally with the K-12 camera during the remainder of the 1930's in an effort to reduce image blur. Although the mount was effective, it was operationally impractical because of the visual method of synchronization that was used.

Between 1937 and 1940, efforts were concentrated on raising the operational altitude of night photography from 2,000 ft. to 4,000 ft. to meet new military requirements. To accomplish this with existing illuminants required that the percentage of light utilized by the camera be increased. This was done experimentally by modifying the K-12 camera shutter and shutter trip unit so that the shutter would open prior to the illuminant burst and be closed immediately after the light peak by the flash detecting equipment. On the basis of the then existing 46 millisecond shutter lag and 100 millisecond flash duration, this shutter mode had the effect of using the first half rather than the last half of the total burning time of the illuminant. Because the peak light output of the flash bomb was used, there was a significant increase in light utilization and a corresponding increase in operational altitude to 5,000 ft. However, since the duration of exposure was essentially unchanged from that obtained in the synchronous mode with 1/25 second shutter speed, the resulting photographs were excessively blurred and the equipment was not put into general service.

In 1940, the FC&IC produced a new shutter and shutter trip unit for the K-12 camera with a shutter opening time lag of 12 milliseconds as contrasted with 46 milliseconds time lag for the original K-12 equipment. By using a greater portion of the peak light output of the flash cartridge, the light utilization was increased 60%. This same shutter design was incorporated in the K-19 camera which became the standard night camera for the Navy in 1941. In spite of the still greater light utilization afforded by capping shutter operation, the resulting pictures were generally of poorer quality than those taken with synchronous equipment because of the blur caused by image motion. Consequently, the synchronous shutter mode was retained as the operational system for the fleet during the war years. In 1947 the FC&IC brought out the K-37 night camera and flash detector shutter trip unit. While the shutter was essentially the same as the improved shutter brought out in 1940 for the K-12 camera with a time lag of 12 milliseconds, the flash detector was far more sensitive, being capable of responding to the ground reflected illumination of the photo flash bomb. Previous flash detectors had to be oriented to pick up the direct air burst flash of the bomb.

Although synchronous shutter operation was the mainstay of night photography during the 1940's, its relatively inefficient use of light provided a constant motivation to develop new techniques. Since the primary objection to the use of capping shutter operation lay in the resolution loss caused by image motion, the advent of the image tracking, moving film principle embodied in the continuous strip cameras released in 1941 reawakened interest in capping shutter operation. In 1947 the U. S. Air Force equipped an A9A type magazine with a moving film IMC attachment and used it with a K-22 camera in a capping shutter operation. Simultaneous night airborne exposures were made with this camera and a K-19 camera operating in a synchronized shutter mode. The resulting photography clearly indicated the advantages of the capping shutter moving film combination in regard to providing improved negative density without a corresponding loss in image clarity. However, this information did not immediately change night photographic techniques which remained geared to the synchronous shutter mode.

With the advent of the small photo flash cartridge and multiple chamber ejectors early in the 1950's, the fighter type aircraft was able to assume the role of a night photographic vehicle previously held only by medium and heavy bomber type aircraft. Among the first aircraft to be equipped with multiple chamber cartridge ejectors were the F2H and the F9F-5P which employed the then currently operational K-37 night camera in their photographic system. The flash cartridges used in the multiple chamber ejectors had been developed for a maximum light output/weight ratio and the flash mixture contained additives that increased the particle dispersion and the combustion rate with the result that the peak light output was reached in 3 to 4 milliseconds. When used with the 12 millisecond lag time of the K-37 shutter, the effect was to reduce the percentage light utilization far below practical limits. This situation motivated a consideration of the use of capping shutter operation with a moving film IMC magazine. The latter type of magazine had become a standard item for day photography but was not utilized extensively for night photography. In 1953, the Aeronautical Photographic Experimental Laboratory (APEL) undertook the task of modifying the shutter assembly of the K-37 camera for capping shutter operation while the CAI modified the MA-10 magazine to provide an end of cycle trip pulse for opening the shutter. Although subsequent tests by the APEL of the modified equipment installed in the F2H aircraft were deemed successful, release of the K-47 night photographic system in 1954 obsoleted the K-37 camera.

The significant feature of the K-47 camera was the incorporation of the "Rapidyne" shutter developed by FC&IC. This shutter utilized separate opening and closing shutter blade assemblies which were independently actuated by externally produced trip pulses with a precisely variable time base separation to provide remote control of the shutter speed. Both the opening and closing speeds of the two blade assemblies were fixed and the time lag of the opening blades was reduced to less than 4 milliseconds so that synchronous operation with the M-112 and M-123 flash cartridges could be obtained. The complete K-47 night photographic system was capable also of advance open and recycle open capping shutter operation when used with the Air Force UCCS camera control system. Because the volume and weight of the control equipment placed serious restrictions on its use in fighter type aircraft, the Bureau of Naval Weapons (BuWeps) requested CAI to recommend means of simplifying the K-47 system for the F3H photographic aircraft. A full flash duration capping shutter system for use with the M-112 and M-123 flash cartridges was developed by CAI which utilized the MA-10A moving film IMC magazine. However, because the production of the F3H-1P aircraft was canceled, the simplified system was incorporated in the F9F-8P in 1955-56 as a part of the operational night photographic equipment of that aircraft.

II. PRESENT METHODS AND EQUIPMENT

The F9F-8P was the current fighter type photographic aircraft in fleet use at the time the subject project was established in June 1956. This aircraft utilized the NCCS-3 & 4 camera control system which was capable of controlling the K-47 camera in a recycle open full flash duration capping shutter mode. Essentially, this system opens the "A" blades of the Rapidyne shutter at the termination of the film transport cycle of the camera magazine and closes the "B" blades after the full burning time of the cartridge by means of a flash detector and a suitable time delay component. In addition to providing the maximum altitude capability for any given pyrotechnic cartridge through 100% light utilization, the capping shutter mode was potentially able to use simpler, more reliable and more compact control system components as well as a simple, relatively slow acting capping shutter. However, since the K-47 camera had become the standard night aerial camera for Navy use and embodied the fast acting Rapidyne shutter, simplification of the control system with a reduction in weight of approximately 15 lbs. over the complete K-47 control system was really all that the capping shutter mode accomplished. Actually, the complete K-47 camera system was already capable of the recycle open capping shutter mode along with the synchronous mode and the advance open capping shutter mode. The latter mode required the memory delay circuitry of the Air Force UCCS camera control system and hence was not usable in Naval aircraft.

The recycle open, capping shutter control system used in the F9F-8P aircraft employed a Model K-47 flash detector manufactured by CAI as Part No. 1025-100. This unit was designed specifically for capping shutter control and had a built-in fixed time delay of 160 milliseconds between flash detection and issuance of the shutter closing pulse. Either M-112 or M-123 flash cartridges can be ejected vertically downward from Lambert Eng. Co. type A-6 or B-4 launchers installed in external, bomb rack suspended containers. The MA-10A IMC magazine, which must be used with the K-47 camera to reduce forward flight image movement during exposure to acceptable limits, received its speed control from the estimated V/H values set into the manual computer of the NCCS-3 and 4 camera control system. The night photography produced by the full flash duration capping shutter system installed in the F9F-8P aircraft was not consistently satisfactory in fleet operation. A large percentage of the photographs showed evidence of excessive image movement during exposure and there were occasional negatives which showed varying degrees of fogging that was believed to be caused by the scattering of non-image forming light from reflective surfaces within and adjacent to the camera lens.

The Air Force had made extensive studies and developed mathematical relationships between the source illumination and the ground illumination which produced useful data and guidance for the accomplishment of high altitude night photography with the M-120 type flash bomb. In the operational area of low altitude night photography using the M-112 and M-123 flash cartridges, no such studies had been made and specific guidance data in the form of Navy publications were not available. The CAI did compile some useful data which was published late in 1956 under the title "Night Photography Data." This report was prepared for BuWeps and was heavily slanted in the direction of the full flash duration capping shutter system developed by CAI for the F9F-8P aircraft which somewhat limited its general usefulness. Actually, it was entirely possible to install the complete K-47 night system in some of the larger photographic aircraft such as the AJ-2P so that both the synchronous and recycle open shutter modes would be available for use with the low altitude flash cartridges. As a result, some squadrons were producing synchronous mode night photography with the improved picture quality inherent in the shorter exposures possible with this system while other squadrons were producing capping shutter mode photography where errors in V/H manual imputs and the effects of aircraft roll, pitch and yaw are greatly magnified by the longer exposure period to produce considerable image degradation. Because neither the photo-optical scanner nor the traveling grid viewfinder can be used at night to accurately determine image speed, and because the degree of air turbulence as well as the pilots proficiency in maintaining straight and level flight can vary considerably, it is understandable that consistently good photography can not be expected in the full flash capping shutter mode. It should be remembered that this mode was originally developed for the K-37 night camera where it served to offset the loss in light utilization which resulted from the synchronized operation of the 12 millisecond lag time K-37 shutter with the 3 and 4 millisecond peaking time of the M-112 and M-123 flash cartridges. With the advent into the fleet of the K-47 night photographic system, extremely versatile shutter modes were potentially available including both full synchronous operation and recycle open with synchronous closure at preselected delay periods after flash detection. It is believed that there were several factors which may have brought about the acceptance of the full flash duration capping shutter control system for the K-47 camera in both the F9F-8P and F8U-1P aircraft with the consequent sacrifice of the operational flexibility inherent in the complete K-47 night system. One factor was apparently the operational requirement for maximum altitude capability which may have been a carry over from the K-37 night camera system where the full flash mode provided a dramatic increase in altitude capability over the then available synchronous mode for the K-37 camera. Another factor was the simplicity and increased reliability claimed by the CAI for the capping shutter system as compared to the full synchronous and recycle open-synchronous closure modes of the complete K-47 system. In the light of the frequent failures and generally unreliable performance of the original Rapidyne shutters this was probably a valid claim at the time, since the capping shutter mode did not rely on the rapid opening and closing features of the Rapidyne shutter nor did it require use of the complex type E-1 shutter speed timer. Although the penalties involved in the use of the full flash duration capping shutter mode were apparently not fully recognized by fleet operating units, the fact that the resulting night photography was generally unacceptable was recognized and clearly indicated the need for a complete evaluation of current night photographic methods, techniques and equipments with a view toward further development and improvement. To this end the BuWeps established the continuing project TED ADC PH-4581 of which the subject report constitutes the phase on low altitude pyrotechnic flash night photography. The basic purpose of this project phase was to determine the parameters affecting the quality and operational limits of low altitude pyrotechnic flash photography and to establish firm relationships and guidance data that would both improve the usefulness of present equipment and point out specific areas where further development is required.

III. PROGRAM OF OPERATIONAL EVALUATION

A. General

The general program was broken down into several areas of investigation which included lens flare, burst orientation, shutter modes, image quality and operational limitations. Actually, these areas are interrelated to a considerable extent but for the purpose of description, they will be treated in the order listed. In making this evaluation, both laboratory and airborne tests were performed. The flight test vehicle used for the majority of the photographic runs was the P2V-5F aircraft Bu No. 131456, while a limited number of runs were made with the F9F-8P aircraft. The bomb bay of the P2V-5F aircraft was modified to accept a multi-camera installation as shown in Figure 1. Two separate camera control systems consisting of an NCCS-3 control system from an F2H-2P aircraft and an NCCS-4 control system developed for the F3H-2P aircraft were utilized to operate the various K-47 cameras. Two external capsules of the type developed for the F2H-2P aircraft containing Lambert Engr. Co. type A-6 cartridge ejectors were installed under the wing on the Aero 14-B combination bomb racks of the P2V-5F aircraft to provide vertically downward cartridge ejection. However, there was no cartridge ejection pod available for test of the upward and side cartridge ejection characteristics. To provide a suitable test vehicle, the port wing tip tank of the P2V-5F was modified to accommodate an A-6 ejector for upward firing and an A-7 ejector for horizontal firing. The night photographic runs were made over Wallops Island off Chincoteague, Va. Although this swampy area was lacking in sharply defined ground details, it was recognized that it represented an excellent example of low contrast terrain and that any night capability demonstrated over such an area would be valid for any terrain likely to be encountered. Five sets of high contrast resolution targets were painted on canvases, each measuring 20 by 20 ft. while smaller resolution targets were painted on 4 by 8 ft. masonite boards.

B. Lens Flare

Four methods calculated to reduce or eliminate the effects of lens flare were applied to the K-47 cameras. The first method consisted in the local fabrication of a conical lens shade covered with dull black cotton flocking which extended about 13 inches beyond the end of the K-47 lens cone. This lens shade can be seen installed on the K-47 camera shown in Figure 1, on the left side. The second method consisted in the installation of three thin metal annular plates or baffles coated with non-specular black paint within the lens cone perpendicular to the optical axis, the blackening of the edges of the lens elements and the extra blackening of reflective surfaces within the lens cone. The third method consisted of the combination of the first and second methods. The fourth method consisted of the combination of the third method, plus the use of infrared film in a camera that had been refocused for the infrared portion of the spectrum. No laboratory tests were made in connection with the lens flare problem since a rather complete study had been made by the Eastman Kodak Co. for the Air Force in connection with high altitude K-47 photography using the M-120 flash bomb. This study revealed that a minimum burst point train angle of 38° could be tolerated without introducing lens flare provided a 12 inch lens shade was used. It was also found that if the burst point could be maintained at a trail angle in excess of 54°, no flare problem would exist even without a lens shade. In regard to burst point positioning, it should be remembered that with the high altitude flash bombs considerable control can be exercised through manual wide range adjustment of the mechanical fuse and by changing the ballistic performance of the bomb through the addition of trail plates and spoiler rings in accordance with the data provided in photoflash bomb drop tables. On the other hand, the low altitude flash cartridges have a ballistic path that is fixed by the air speed of the aircraft, the muzzle velocity of the cartridge and the orientation of the ejector. Since the latter two factors are fixed by the ejector installation and the particular cartridge in use, the burst point position can be controlled only by airspeed and the limited preselection of cartridges with fixed powder train fuse delay periods. Because the operational airspeed of the P2V-5F flight test aircraft was less than 200 knots, it was expected that marginal flare conditions would exist during some of the photographic runs with downward cartridge ejection, especially when using the 1 and 2 second fuse delay cartridges. It was in this area that the various methods of lens flare prevention would be given a true operational test. One source of image veiling reflection that was not studied, concerns the reflections between the camera lens and the camera port glass. Primarily, this was not done since the Air Force had made an exhaustive study of the problem in connection with the photographic installation in the RB-66 aircraft and had found a solution in tilting the glass port forward with respect to the camera axis. Actually, this potential source of lens reflection did not exist in the P2V-5F installation since the cameras looked through the open bomb bay doors.

C. Burst Orientation

Early in the planning stages of the subject project, it was recognized that upward ejection of the flash cartridge would provide several operational advantages. The principle advantage that was expected was the complete elimination of the lens flare problem. A secondary advantage was that a more even illumination of the camera field of view would result from the higher burst height of the cartridge which reduces the difference in slant range distances from the burst to the forward and rear edges of the field of view. A still further improvement in uniformity of illumination was anticipated through the use of short fuse delay cartridges which would reduce the horizontal trail distance of the burst point without introducing the lens flare problem that occurs with short trail distances when using downward cartridge ejection. In addition to upward ejection, several photographic runs were planned using horizontally outward ejection to determine if a lower burst height could be tolerated without introducing lens flare.

D. Shutter Modes

With the two control systems that had been installed in the P2V-5F flight test aircraft, it was possible to operate the K-47 cameras in either the full synchronous shutter mode or the recycle open-synchronous closure shutter mode using the full range of shutter speeds available in the Type E-1 Shutter Speed Timer. In the full synchronous mode, the highly sensitive Type C-1 flash detector, which has a practically zero lag time, detects the cartridge burst at an extremely low light level which initiates a trip pulse to the opening blades of the "Rapidyne" shutter through the E-1 shutter speed timer which in turn initiates a preset delay pulse (equal to the shutter speed setting) to the closing blade assembly of the shutter. The average time for the Rapidyne shutter to fully open after receipt of a pulse has been determined to be four milliseconds of which two millisecond represents the operating time of the shutter trip mechanism and two milliseconds the actual opening time of the shutter blades. In planning the full synchronous mode photographic flight tests, only the 1/50 second and 1/100 second shutter speed settings were used. A minimum speed of 1/50 second was selected since the next slower setting of 1/25 second would have spanned the entire burning time of the cartridge and thereby defeated the exposure shortening feature of the synchronous shutter mode. The maximum speed of 1/100 second was selected since the next higher speed of 1/200 second would have reduced the light utilization percentage to approximately 1/3 of the total light output of the cartridge. It was not considered that the slight potential increase in image clarity afforded by the shorter exposure time would justify the appreciable loss that could be expected in operational altitude.

In the recycle open-synchronous closure shutter mode, the trip pulse to the opening blades of the Rapidyne shutter is initiated by the completion of the winding cycle of the shutter blades. This control arrangement does not provide the true recycle open shutter operation that was originally conceived and developed by the APEL for the K-37 camera. The basic concept was that after the capping shutter had been tripped closed by the flash detector, it should remain closed during the subsequent film transport period so that ground lights or fires could not record on the film during its non-IMC movement. To accomplish this type of operation, the trip pulse to the opening blades should be initiated by the completion of the film transport cycle rather than the shutter wind cycle unless the two cycles happen to be identical in length. Since the winding cycle of the Rapidyne shutter in the K-47 camera is roughly one half that of the MA-10A moving film IMC magazine, it is possible to get more ground light streaking in the recycle open shutter mode of the complete K-47 control system than in the simplified K-47 system unless the operating instructions to use this system only in the complete absence of ground illumination are adhered to. The synchronous closure of the Rapidyne shutter in the recycle open mode is accomplished in the same manner as in the full synchronous mode since the trip pulse generated by the flash detector for actuating the opening shutter blades is diverted to ground through a resistor by the mode selector switch. Thus, the shutter speed setting on the T-1 shutter speed timer control is equivalent to the time delay after peak light output for the closing shutter to fully close since the rise time of the cartridge burst is practically equal to the closing time of the shutter after receipt of the trip pulse. By preselecting various shutter speed settings on the T-1 timer control, the amount of decaying light that is cut off by shutter closure can be controlled through a range that includes full flash duration exposures on the one extreme to synchronous closure exposures utilizing less than 50% of the total light output of the flash cartridge on the other extreme. In planning the recycle open-synchronous closure photographic flight tests, the 1/25, 1/50 and 1/100 second shutter speed settings were used. A minimum speed of 1/25 second was selected since it delayed closure of the shutter beyond the full burning time of the flash cartridge and thereby duplicated the recycle open, full flash duration mode of the NCCS-3-4 control system installed in the F9F-8P aircraft. The 1/50 and 1/100 second shutter speed settings were used to determine which setting represented the best compromise between altitude capability and image clarity. It should be noted that the control system in the F9F-8P aircraft does provide true recycle open operation since the tripping of the opening blades is initiated by an "end of recycle" switch in the MA-10A magazine.

E. Image Quality

Prior to the photographic flight tests, certain laboratory tests were performed to ascertain whether there were any inherent characteristics of lens resolution or film flatness during exposure which might constitute limiting factors in the optimum results that could be obtained with the 12 inch f/2.5 lens of the K-47 camera and the MA-10A magazine. The resolution capability, under laboratory conditions, of the average K-47 camera equipped with the 12 inch f/2.5 Eastman Kodak lens was determined. This lens resolved 26 lines/mm on axis, 13 lines/mm at 20 degrees off axis and had a AWAR of 17 lines/mm. Because of the proven quality of day photography obtained with the MA-10A magazine, there was no question of the film flattening and image tracking capability of the magazine in the day mode of IMC where the reciprocating platen moves with the film during IMC under normal vacuum and there is consequently, no relative motion between film and platen during exposure. In the night mode, the film is moved continuously at IMC velocity over a stationary platen under reduced vacuum during the period between the end of rapid film advance and the completion of the flash exposure. In order to eliminate the effects of the less accurate IMC velocities available in night photography where only estimated inputs can be manually set into the V/H computer, the control circuitry of the MA-10A magazine was modified to permit utilizing the continuously moving film IMC in daylight photography where scanner controlled IMC can be used. With an accurate V/H input as a common denominator, it was felt that a valid comparison could be made of the effects of the two methods of IMC on film flatness and image tracking synchronization.

F. Operational Limitations

The variables which affect operational limitations are many and complex and their interaction determines to a considerable degree what the final effect will be. Some variables are easily controllable such as altitude, airspeed, shutter speed, and shutter mode while others are relatively uncontrollable, such as ground reflectance, air turbulance, atmospheric haze, and to a certain extent, burst position. Flight tests were planned through a range of altitudes that were predicted to produce critical IMC conditions on the low end and insufficient ground illuminations on the high end. Due to the flight characteristics of the P2V-5F test aircraft, a range of airspeeds from 150 knots to 190 knots was all that could be anticipated and this range was not expected to materially affect burst position as it relates to lens flare. It was hoped that through the controlled variation of enough parameters, some firm relationships could be established, on the basis of the test photography, for use in obtaining greater usefulness and reliability out of present equipment and delineating areas where further development might be required. Knowing that many of the variables involved in the flight tests were related mathematically in respect to their numerical quantities, it was felt that a mathematical analysis of all the parameters might yield a firmer basis for establishing operational limits and developmental guide lines. The formulation of such a program forms the text of the following section. Much of the formula derivations and computational work was performed under Foundation Research Project TED ADC RS-7045-5925A established at the APEL by the Naval Air Development Center as a Center sponsored effort.

IV. PROGRAM OF MATHEMATICAL ANALYSIS

A. General

There have been several mathematical studies made of the relation between the intensity of the source illumination, the burst position and the scene illumination as it relates to the field of view of the camera. Some studies centered around the determination of the optimum sizes for pyrotechnic illuminants based on airborne weight limitations and maximum reconnaissance capability per mission. Other studies centered around determination of the optimum burst height for the M-120 type high altitude flash bomb as it related to use of the K-47 camera under an assumed set of operating conditions. The CAI made a study that was incorporated in their "Night Photography Data" report previously referred to that attempted to present in graphical form definite operational data for the M-112 and M-123 flash cartridges when used with the K-47 camera. The data consisted of graphs in the form of polygons wherein the area enclosed by each plot included all combinations of altitude and air speed which, for a given flash cartridge and fuse delay, would result in ground illumination within certain arbitrarily established limits. These limits permitted a 10 to 1 variation in the maximum illumination on the flight line through a range from 1.0 to 0.1 ft. candle seconds as determined by the combined effects of altitude and airspeed changes and a maximum flight line range of illumination of 2 to 1 within the camera field of view. A further limitation established by the curves was that the trail angle of the burst would be at least 15 degrees to the rear of the acceptance cone of the camera for prevention of lens flare. The APEL considered that this method of presentation represented a useful tool for the photo-pilot in setting up night photographic missions and predicting with a fair degree of certainty, the quality of the resulting photography. However, it was clearly evident that the arbitrary limits should be revised and re-defined to more accurately delineate the operational area within which satisfactory night photography should be obtainable on the basis of actual flight test data. It must be remembered that even the most exacting theoretical determination of the numerical quantities of factors whose mathematical relationships are firmly established, can only yield light intensity information on the plane of the ground as it relates to the field of view of the camera in use. The actual light falling on the film emulsion and the image density it ultimately produces in the processed film is under the influence of a combination of variables that are not directly related mathematically with the scene illumination on the ground. These variables include ground reflectance, atmospheric haze, exposure time, lens transmission, and film processing techniques. In order to determine what level of scene illumination is required to produce recognizable image density in the negative, the U. S. Air Force made a series of ground instrumented flight tests at Eglin Field, Florida in 1952 under closely controlled conditions. The result of these tests yielded a computed value of .09 foot-candle-seconds for the minimum scene illumination when using a 12" focal length f/2.5 lens with Tri/X film. This value of .09 fcs has been used extensively by the Air Force in several analytical studies and has been more or less established as a standard value in computing the operational capability of various pyrotechnic flash night photographic systems.

B. Minimum Scene Illumination

The factor of minimum scene illumination is by far the most influential of all the factors since it affects both operational flexibility and altitude capability and is intimately associated with the shutter modes of the camera. The CAI plots did not contain lines which defined operating limits on the basis of minimum scene illumination, but rather, it established these limits on the basis of the maximum light falling on the flight line within the field of view of the camera. In line with the philosophy of the Air Force, the APEL considered that a minimum scene illumination of .09 fcs should exist at the forward corners of the field of view of the camera in order to provide recognizable image densities in these areas. It has been variously argued that with 60% forward overlap photography, the forward cover area is not of critical interest. This might be technically correct, but night photography in general, is not concerned with ground mapping and the fall off of illumination toward the forward edge of the negative makes it doubtful if stereo pairs would have any real value. Actually, the principal use of night photography is for ground surveillance and target identification where logistic requirements of maximum ground coverage per pound of pyrotechnic illuminant might dictate a reduction in forward overlap. Fortunately, it is not necessary to resolve this point of argument in order to make use of the minimum scene illumination limits of the operational parameter plots if it is understood that these limits are nominal and are not intended to represent lines of demarcation beyond which no satisfactory photography may be obtained. Referring to Graphs #1 through #8, it should be noted that, instead of a single line of constant scene illumination having the minimum value of .09 fcs, there is a family of lines having values above and below this value wherein each line represents all combinations of flight altitudes and aircraft speeds which will produce the constant values of forward corner scene illumination shown. This method of presentation has several inherent advantages which will be discussed separately. First, since the only camera variables involved in the development of these lines are the cone angle of the lens and the optical axis orientation, these lines are applicable to any vertically installed camera having the same cone angle regardless of format size and lens speed provided the required forward corner scene illumination value is established experimentally. Second, since these lines represent actual forward corner illumination on the ground produced by the full light output of the pyrotechnic illuminant, they can be used for any shutter mode by determining the light utilization percentage of the shutter and applying this as a proportional correction to the minimum scene illumination requirement. Finally, any other changes in the factors which controlled negative density in the night airborne tests used by the Air Force to establish the .09 fcs value, if their proportional effect can be determined, may be applied as a correction factor to the basic minimum illumination figure to establish new operational limits.

The determination of forward corner scene illumination values (Ep), in the camera field of view started with the basic equation for spherical burst illumination which, after a series of substitutions and algebraic expansions shown in Appendix I, took the final form of:

$$Ep = \frac{I\,(H \pm d)}{(1.28\,H^2 + 0.75\,th \pm 2dH + d^2 + t^2)\;3/2}$$

where: - I= Full light output of flash cartridge in candle power seconds.

H= Flight altitude of aircraft in feet

+d= Distance above flight altitude of burst for upward ejection

-d= Distance below flight altitude of burst for downward ejection

t= Trail of burst behind aircraft in feet

Whereas it would have been desirable to express this equation in terms of H so that specific plotting values of Ep could be substituted in the equation, no practical method of factoring out the H term was found. As an alternate solution calculated values of Ep were plotted against the substituted values of H in the above equation using the ballistic coordinates t and d that corresponded to a specific aircraft speed. Three separate curves relating Ep to H were plotted for aircraft speeds of 200, 350 and 500 knots so that three specific combinations of altitude and airspeed would be available for plotting each of the constant Ep lines.

C. Maximum Scene Illumination

The factor of maximum scene illumination does not exert as strong an influence on the operational limitations of the night photographic system as does the factor of minimum scene illumination for obvious reasons. If the complete K-47 night photographic system is available, then the selection of the synchronous shutter mode with appropriate shutter speed settings can be used to restrict exposure when low altitude operation appears to introduce the possibility of over exposure. Even without any remote exposure control, the negative density could be controlled to a certain extent through processing and printing techniques. In the absence of any explanation in the CAI report for the 10 to 1 range limit for maximum flight line illumination values, it is assummed that the arbitrary range is related in some way with the exposure latitude of the film emulsion since the recycle-open capping shutter control system developed by the CAI for the K-47 camera had no provisions for remote control of exposure. In keeping with the flexibility of use achieved with the multiple line presentation of minimum scene illumination, the series of maximum scene illumination lines appearing on the left side of the operational parameter plots shown in Graphs #1 through #8 were developed. Each of these lines bears a ten fold relation with a corresponding minimum scene illumination line so that once the minimum scene illumination requirements have been established, the operational altitude envelope for a 10 to 1 ground illumination range can be read from the plot.

In the mathematical determination of the maximum flight line scene illumination, consideration must be given to the fact that the nadir point of the burst may fall within the field of view of the camera or behind it depending on the relation between the burst point trail distance and the camera field of view under different combinations of aircraft speeds and flight altitudes. It was found that, in general, this point falls within the field of view of the camera or sufficiently close to the rear edge that no significant error is introduced by taking the burst height as the distance to the point of maximum illumination. With the trail distance eliminated, the basic equation for spherical burst illumination can be rewritten in the simple form:

$$H = \sqrt{\frac{I}{Ep}} \pm d$$

where values of H can be solved directly for any assummed value of Ep. Since the effect of aircraft speed on the ballistic drop distance of the cartridge is negligible, the maximum flight line illumination lines appearing on left side of the operational parameter plots are drawn vertical in most cases.

D. Maximum to Minimum Scene Illumination Ratio

Actually, the principle significance of maximum scene illumination does not lie in its function as an altitude limiting factor, but rather in the ratio that it bears with the minimum scene illumination occuring at the same instant within the field of view of the camera. Because this maximum to minimum sceen illumination ratio has a direct bearing on the density range of the resulting negative, it is desirable to indicate on the operational parameter plot where this limiting ratio occurs. A maximum ratio of 2 to 1 was considered a practical limit for optimum night photography in the operational parameter plots of the CAI report. However, it was stated in that report that this ratio can be exceeded by use of longer fuse delays and higher aircraft speeds if greater shadow rendition is desired and if the resulting increase in negative density range can be tolerated. Actually, this greater density range can be accommodated by the use of Log E tronic printing equipment. In order to extend the usefulness of the operational parameter plots into this area, an illumination ratio line of 2½ to 1 and, in some cases, a ratio line of 3 to 1 has been plotted. A direct method was developed for plotting the maximum to minimum ratio lines which gave exact values of H for assumed values of aircraft speed through use of the corresponding trail and drop distances. This method, which eliminated any need for calculating actual scene illumination values, is described in Appendix I.

E. Upper and Lower Limits of Aircraft Speed

On the downward ejection operational parameter plots it will be noted that the bottom is cut off at a definite minimum aircraft speed which corresponds to a burst point trail angle of 35 degrees while above this bottom line is a parallel dotted line corresponding to a burst point trail angle of 50 degrees. The 35 degree burst point trail angle had been previously considered the minimum value which would not cause lens flare and resultant film fogging. As a result of lens flare tests conducted by Kodak and the APEL, a 50 degree burst point trail angle has been found to be a more realistic minimum value for the prevention of lens flare in cameras not provided with special anti-flare devices such as baffling, antireflective coatings and lens hoods. The 35 degree line has been retained in the operational parameter plots since it represents a permissible trail angle for cameras equipped with anti-flare devices. The minimum aircraft speeds which produce these limiting trail angles were found from the ballistic curves of trail and drop versus aircraft velocity for the particular flash cartridge represented by the operational parameter plot. Since the tangent of the trail angle is equal to the ratio t/d, a series of trial computations were used to determine from the ballistic curves, the aircraft speed at which the desired ratio of trail and drop occurred. On the upward ejection operational parameter plots, it will be noted that there are no minimum aircraft speed limitations since the burst occurs above the aircraft where lens flare conditions do not exist. The top cut off line of the plots has been arbitrarily set at 600 knots strictly for convenience in presentation and the plots could be extended beyond this line although ballistic data is not available in this range.

V. DISCUSSION

In correlating the results of the flight test program with those of the mathematical analysis, certain facts became self evident. The test photography consistently showed that adequate forward corner negative density required a higher level of scene illumination than the established value of .09 fcs. This cast some doubt on the validity and method of determination of the minimum scene illumination value of .09 fcs. Through the process of marking on the appropriate operational parameter plots, those combinations of altitude and airspeed in the test photographs which produced usable forward corner image density, it was found that the average full flash scene illumination requirement was about .135 fcs. It should be pointed out that the burst position and illumination characteristics of the flash cartridge used in the plots were based on mathematically computed ballistic data and statistical light output data rather than from actual test data recorded by a complex system of ground instrumentation. However, the consistent agreement between the test photography and the operational plots, once the value of .135 fcs. was established and recomputed for the various shutter modes, indicated that the source of data was not the controlling factor in creating the apparent lack of configuration between the plots and flight tests in regard to operational limitations.

Other variable factors which control negative density such as terrain reflectance, atmospheric haze and film processing techniques were considered, but their effect on a percentage basis was determined to be far too small to account for the difference between the calculated and experimentally determined minimum scene illumination requirements. The one factor, possibly not considered by the Air Force investigators in their determination of minimum scene illumination from instrumented flight test data, was the effect of off-axis lens transmission fall off. A curve of off-axis light transmission values for the K-47 lens was obtained from the Eastman Kodak Co., and was used to calculate the corrected value of scene illumination required in the forward corners of the field of view of the camera. This calculated value, on the basis of the best available information regarding the position on the Air Force test photograph of the point of minimum acceptable density, was found to be approximately .135 foot-candle-seconds.

Figure 2 shows the lens flare or internal reflection resulting from a small trail angle burst position without the benefits of internal baffling on an external lens shade. Figure 3 shows the complete absence of lens flare resulting from the use of an external lens shade under conditions of a small trail angle burst position. In Figure 4 may be seen the results of a fairly high level of non-image-forming negative density covering the rear third of the negative. This is attributed to a small trail angle burst position in combination with atmospheric haze. Figure 5 shows a complete absence of the effects of non-image-forming negative densities when the trail angle of the burst position is increased (note longer shadow on water tank as compared to Figure 4) by a longer fuse delay and higher aircraft speed. However, it should be pointed out that with downward ejected cartridges bursting at or slightly behind the minimum trail angle, there is always the chance that a slight nose down attitude of the aircraft at the time of exposure could produce non-image-forming densities on the negative. Figure 6 shows the improvement in overall information content when using infrared film under the same conditions of illumination that existed in Figure 5. Although the contrast of man-made objects with the surrounding terrain is somewhat reduced, the contrast and image detail of vegetation and ground terrain is considerably increased over that obtained with panchromatic film. The overall effect of Figure 6 is that more uniform and more intense ground illumination was available than in Figure 5 whereas, actually, the infrared film is sensitive to a large part of the energy output of the flash cartridge that is unavailable for forming image densities on normal panchromatic black and white film. The additional ability of infrared film to penetrate haze is not necessarily demonstrated by Figure 6 due to the relatively large trail angle burst position. However, had the small trail angle condition of Figure 4 existed in Figure 6, it would be reasonable to expect a considerable improvement over Figure 4.

The value of upward ejection was fully confirmed by the test photography in respect to its ability to completely eliminate lens flare as well as significantly reduce non-image-forming densities due to atmospheric haze. The resulting photography as shown by Figures 7, 8, 9, 10, exhibits a uniformity of exposure across the format that somewhat resembles daylight photography. The anticipated loss in operational altitude over downward ejection seemed to be offset by the increase in uniformity of negative density so that the percentage of total format area containing usable image detail was as great or greater than with downward ejection. One of the causes for this apparent paradox stems from the use of short fuse delays which results in a relatively small increase in burst height from downward to upward ejection. Another factor which operates to produce this paradox is the small percentage change in slant range between cartridge burst and the forward corner of the field of view which is evident when comparing downward and upward ejection. Coupled with this is the fact that the angle of incidence of the light reaching the forward corner decreases with increase of burst height for a fixed flight altitude and tends to offset, to some degree, the loss of forward corner illumination that would otherwise be expected from the lengthening of the slant range. By using the information in the operational parameter plots included in this report, it is possible to obtain the following interesting comparative figures. The loss in operational flight altitude for constant forward corner illumination when changing from downward to upward cartridge ejection with a 1 second fused, M-112 cartridge is 6%. The loss when making the same change with a 2 second, M-112 cartridge is 8%. The loss in operational flight altitude is actually greater when changing from a 1 second to a 2 second fused, M-112 cartridge, the average loss for either downward or upward ejections is 12%. An interesting thing occurs when the fuse delay is reduced from 2 seconds to 1 second when changing from downward to upward **ejection.** Under these conditions, a net gain of 5% in flight altitude results. From these figures it is obvious that upward ejection of short fuse delay cartridges gives the optimum overall operational capability to the pyrotechnic flash, night photographic system. However, in existing aircraft where downward ejection must be used, the test photography confirms the fact that this mode can be tolerated provided the minimum airspeeds shown on the operational parameter plots are observed along with the necessary provisions for prevention of lens flare. The only possible advantage to be gained by longer fuse delays would be the shadow producing effects on three dimensional objects of an increase in the angle of incidence of the light. However, this advantage must be viewed in the light of the accompanying disadvantages of reduced forward corner illumination or reduced operational altitude plus an increase in negative density variation over the format. Because of the questionable value and limited usefulness of the four second delay M-112 cartridge and the six second delay M-123 cartridge, operational plots for these cartridges are not included in this report and it is suggested that their use be discontinued.

It should be noted that the operational parameter graphs developed in this report can be used with any aerial camera having a 41 degree angular coverage lens provided upward or downward ejected M-112 or M-123 flash cartridges are used and a series of night photographic runs for calibration purposes are made. The calibration runs would be made at altitudes from 1,000 ft. to 5,000 ft. in increments of 500 ft. maintaining a constant airspeed and using any one of the available K-47 shutter modes. A shutter mode peculiar to the test camera could be used provided it was possible to determine its light utilization percentage in respect to a particular pyrotechnic illuminant. The film would be processed according to established procedures for night photography. The negatives would be analyzed to determine the highest operational altitude for which a negative having adequate image density in the forward corners is obtained. It will be noted that the slopes of any two successive minimum scene illumination lines do not vary to any great degree. Accordingly, the altitude and aircraft speed of the selected negatives is marked on the graph corresponding to the cartridge, fuse delay and launching orientation used in the test and a line is drawn through this point parallel to closest adjacent forward corner scene illumination line. The minimum acceptable forward corner scene illumination value obtained for a particular shutter mode with the appropriate operational graph is applicable to the other graphs included in this report and eliminates the requirement for performing any additional flight tests. Using the minimum scene illumination determination made with a single flight test, these lines can then be drawn on the other graphs to obtain operational guide lines for any selected combination of fuse delays, cartridge types and ejector orientation. In order to obtain minimum scene illumination lines for shutter modes other than the one used in the flight tests, the previously established light utilization percentages for the various K-47 shutter modes should be used in accordance with the following formula:

$$\text{Ep (for any selected shutter mode)} = \frac{\text{light utilization percentage for flight test shutter mode}}{\text{light utilization percentage for selected shutter mode}}$$

The light utilization percentages for the three shutter modes shown on the graphs has been established at 100% for recycle open-full flash, 65% for recycle open-synchronous closure at 1/100 second and 50% for full synchronous at 1/100 second.

VI. CONCLUSIONS

1. The operational parameter graphs included in this report can be used as a useful guide for the performance of night photographic missions with the vertically installed K-47 camera when using the M-112 and M-123 pyrotechnic flash cartridges. These graphs can be adapted to provide

operational data for other lenses of the same angular coverage by making a single night photographic calibration flight. The graphs also provide a mathematical basis for comparing the effects on altitude capability of ejection orientation, shutter modes, fuse delays and aircraft speeds.

2. The average reduction in operational altitude when changing from downward to upward cartridge ejection while maintaining constant forward corner scene illumination is 225 ft. for the M-112 cartridge and 350 ft. for the M-123 cartridge. On a percentage basis this amounts to 7% of the full flash altitude capability of either cartridge. In view of the fact that upward ejection completely eliminates lens flare, reduces the non-image-forming negative densities caused by atmospheric haze and provides more uniform ground illumination, the improved photography more than offsets the mathematically computed altitude reduction.

3. In the upward cartridge ejection orientation, the use of the longer fuse delays causes a loss in operational altitude at all airspeeds with the loss becoming more pronounced as airspeed is increased. The average loss in operational altitude per 100 knot increase in aircraft speed is 300 ft. for the four second delay and 100 ft. for the two second delay M-123 cartridge. The loss is 150 ft. for the two second delay and 75 ft. for the one second delay M-112 cartridge. In addition to a loss in operational altitude, the longer fuse delays result in a larger ratio of maximum to minimum scene illumination which produces negatives that usually require special dodging techniques in printing. In upward ejection, the fuse delay becomes more of a safety of flight measure rather than a device for placing the air burst of the cartridge in the best possible position.

4. Where downward cartridge ejection orientation must be used due to the configuration of existing aircraft, then the minimum aircraft speeds shown on the operational graphs would have to be observed. For unbaffled and unshaded lens cones, the minimum speed is 245 knots for the two second M-123 cartridge, 210 knots for the four second M-123 cartridge, 216 knots for the one second M-112 cartridge, and 170 knots for the two second M-112 cartridge. It should be stressed that these values are marginal and a slightly nose down attitude of the aircraft at the instant of exposures or excessive atmospheric haze could cause some fogging and flare even with these minimum airspeeds. Where operational airspeeds close to or below these minimum values are required, then baffling and lens shading techniques would have to be employed. The only alternative would be to tilt the optical axis of the camera forward, provided the resulting reduction in forward corner scene illumination and lack of verticality would be acceptable. In downward ejection, the use of the longer fuse delays caused a loss in operational altitude at all airspeeds with the average loss per 100 knot increase in airspeed being greater than for upward ejection.

5. The selected shutter mode has, by far, a greater effect on the maximum altitude capability of a particular pyrotechnic than any of the other controllable parameters. The recycle open-full flash duration shutter mode naturally gives the highest altitude capability since it represents 100% light utilization. However, the resulting photography is generally considered unacceptable due to image degradations resulting from errors in

forward image motion compensation and uncompensated changes in aircraft attitude occurring during the relatively long (1/30 sec.) exposure period. The full synchronous shutter mode with a speed setting of 1/100 second provides the shortest practical total exposure time, but utilizes only 50% of the full flash light output of the cartridge. The increased resolution provided by this shutter mode is accompanied by a loss in full flash altitude capability of 34%. The most practical compromise between resolution loss and operational altitude loss is considered to be the recycle-synchronous closure shutter mode with the shutter speed closure set at 1/100 second after the peak light output of the cartridge. This mode results in full flash altitude capability loss of only 22%, and provides night photography with acceptable image quality.

6. The use of fully stabilized camera mounts and improved accuracy in the V/H input signal could measurably increase the quality of the night photographic image. While no attempt was made to establish these conclusions experimentally in the operational flight test program, they are factors which are known to improve daylight photography. These same factors would be even more applicable to night pyrotechnic photography where the exposures are necessarily longer. Although stabilized mounts are available for some aircraft, the signal for control of forward flight IMC in night missions is currently based on setting into the computer, the best estimate of ground speed and altimeter reading. The need for an operational night image velocity detector continues to exist and some progress is being made toward satisfying this need.

7. The pyrotechnic flash cartridge continues to be a major factor in limiting the full effectiveness of the night photographic system. A more accurate time delay between ejection and bursting of the cartridge is a continuing requirement. The ± 10% tolerance of the present powder train fuse is excessive and complicates the shutter synchronization problem. A reduction in the total burning time of the pyrotechnic mixture would aid materially in simplifying shutter design and control circuitry. In the light of the proven superiority of the short delay, upward ejected cartridge, it is believed that further improvement of the night photographic system could result from the development of a pneumatic or mechanical cartridge ejector and an electric thermal or mechanical burst delay mechanism.

8. The limited flight tests with infrared film have demonstrated that more uniform negative densities and increased target information over certain types of terrain can result from the use of these materials.

9. The off axis light transmission fall-off of the K-47 lens has been found to have a greater contributing effect to underexposure in the forward corners of the negative than the light distribution in the field of view of the camera. Further study will be required to fully develop a correlation between these two effects on negative density. It is considered that the design requirements for future night camera lens development will have to stress to a greater extent, the off axis light transmission characteristics of the lens.

VII. RECOMMENDATIONS

1. The operational parameter graphs included in this report should be considered for preparation into a form suitable for issuance to fleet operating units as a guide for planning low altitude night reconnaissance missions when using the M-112 and M-123 flash cartridges with a vertically installed K-47 camera.

2. Upward cartridge ejection is recommended as the optimum means of eliminating lens flare, reducing the adverse effects of atmospheric haze, and improving the uniformity of scene illumination within the field of view of the camera.

3. The use of the short fuse version of each flash cartridge is recommended since such use provides the maximum altitude capability and the greatest uniformity of scene illumination. In upward ejection, nothing is gained by long fuse delays unless the modeling effect of long shadows is considered more important than the two advantages previously mentioned. In downward ejection, the use of the longer fuse delay may be required to control lens flare, especially at the slower aircraft speeds.

4. Where downward ejection must be employed, due to aircraft configuration, it is recommended that the camera be equipped with a lens shade and/or internal baffling in order to provide a lower limit to the operational envelope of aircraft speeds within which lens flare is not a problem. In cases where baffling or lens shading is not feasible, it is recommended that the minimum aircraft speeds shown on the operational graphs be observed or the optical axis of the camera be tilted forward.

5. It is recommended that the recycle open-full flash shutter mode, which is the only mode available in the NCCS-4 control system, should not be used in the performance of pyrotechnic flash night photography. The image degradation produced by exposure during the full burning time of the flash cartridges (30 to 40 milliseconds) makes the resulting photography unacceptable. Under conditions where maximum operational altitude is of prime importance, the marginally thin negative produced by the recycle-open, synchronous-closure shutter mode generally contains more information content than the denser negative produced by full flash duration exposure.

6. It is recommended that the Night Timer Unit, Chicago Aerial Industries Part No. 1262-100, with fixed delay, be modified or replaced with a timer unit adjustable from 5 to 25 milliseconds. See Recommendation 6b, of NADC Report AP-L5925 of 28 December 1959. Such a timer is in routine use at this laboratory.

7. It is recommended that the K-47 Camera System (T. O. 10A1-5-18-1), be modified in accordance with Appendix III to provide for opening the shutter with an end-of-film-advance trip pulse in lieu of the existing end-of-shutter-wind trip pulse. This modification will reduce the streaking of ground luminous targets.

8. The advance-open, synchronous-closure shutter mode, which is a U.S. Air Force requirement and is available in the complete K-47 camera control system is not considered to offer any operational advantages over the other shutter modes, except under conditions of strong ground lights or fires. By use of a programmed shutter opening pulse, which is not available in Navy camera control system, the shutter open time before cartridge burst is held to a minimum. Its primary advantage would be for use with high altitude pyrotechnic flash bombs where the relatively long picture taking interval would cause an excessively long shutter open period with the re-cycle open shutter mode.

9. The full synchronous shutter mode with a shutter speed setting of 1/100 second should be incorporated in the existing Navy camera control system for use with the K-47 camera. This mode would be especially valuable at the lower ranges of altitude where the excess of scene illumination would permit the shorter exposure period of this low light utilization shutter mode to reduce image degradation resulting from the higher forward flight image velocities encountered at the lower altitudes.

10. It is recommended that fully stabilized camera mounts be used with all operational shutter modes of the K-47 night camera where installation space will permit. It is an established fact that the use of stabilized mounts will significantly improve image definition, especially under the recommended exposure period of 1/100 second available in the night shutter modes of the K-47 camera.

11. Since the effectiveness of the forward flight image motion compensation required in night pyrotechnic flash photography depends to a considerable extent on the accuracy of the V/H input signal, it is considered essential to improve this accuracy through further development effort. The use of Doppler radar in combination with a radio altimeter to produce automatically an accurate V/H input into the camera control system is currently being explored by the APEL under Project TED ADC PH-5068. Other methods, including infrared, should be fully explored.

12. The low altitude pyrotechnic cartridge should be subjected to further development. The fuse delay errors should be eliminated or reduced to acceptable limits. The burning time of the cartridge should be reduced to the greatest extent possible. It is considered that a reduction in burning time from 30ms. to 10ms., if it could be accomplished without a significant loss of total light output, would permit reduction in the night system complexity by permitting satisfactory use of cartridges in the full flash duration capping shutter mode. The use of this mode would extend altitude capability without the loss of image definition currently associated with this mode.

13. The use and potential advantages of infrared film when used in conjunction with pyrotechnic flash cartridges should be subjected to further exploratory development. Such development should consider the effects of various type of terrain as well as the spectral composition of the pyrotechnic mixtures.

14. It is considered that lenses designed for use in night photography should feature minimum off-axis light transmission fall off.

APPENDIX I

A. Minimum Scene Illumination Computations

The determination of minimum scene illumination values (Ep) in the forward corners of the field of view of the camera starts with the basic equation for spherical flash illumination where the subscripts MIN are used to denote a particular relation to minimum scene illumination:

$$E_p = \frac{I \cos i}{D^2} \tag{1}$$

which by the simple substitution of:

$$\cos i = \frac{h}{D_{min}} \quad \text{and} \quad h = H \pm d \quad \text{(FROM FIG. 1)}$$

reduces to

$$E_{p\,min} = \frac{I(H \pm d)}{D^3_{min.}}$$

which, for convenience of substitution of D^2 values, may be rewritten as follows:

$$E_p = \frac{I(H \pm d)}{(D^2_{min.})^{3/2}} \tag{2}$$

and where (from Fig. 1):

I = Total light output of flash cartridge - candle power-seconds.
i = Angle of incidence to the normal of the illuminated area.
D = Slant range from burst to forward corner of field of view.
h = Burst point altitude.
* +d = Distance of burst above flight altitude for upward ejection.
* -d = Distance of burst below flight altitude for downward ejection.
H = Flight altitude of aircraft.
t = Trail of burst point behind aircraft.

From the geometry of the camera and burst point shown in Fig. 1, the (D^2) factor in equation (2) can be related to H, t and d in the following manner:

$$D^2_{min.} = h^2 + R^2 \tag{3}$$

$$\text{and} \quad h^2 = (H \pm d)^2 \tag{4}$$

$$\text{and} \quad R^2 = (H \tan \theta)^2 + (H \tan \theta + t)^2 \tag{5}$$

Substituting equations (4) and (5) in equation (3) gives

$$D^2_{min.} = (H \pm d)^2 + (H \tan \theta)^2 + (H \tan \theta + t)^2$$

which, after expanding and collecting terms becomes

$$D^2_{min} = (1 + 2\,\overline{\tan \theta}^{\,2})H^2 \pm 2dH + 2 \tan \theta\, t\, H + d^2 + t^2.$$

*NOTE: Wherever double signs appear, the upper sign is used for upward ejection and the lower sign for downward ejection.

Substituting the numerical value of tan θ = .375 for the 41° angular coverage of the K-47 lens in the preceeding equation gives:

$$D^2 min. = 1.28H^2 + .75tH \pm 2dH + d^2 + t^2 \qquad (6)$$

Substituting the value of D^2 from equation (6) in equation (2) gives the following equation for the value of Ep in terms of I, H, t and d:

$$Ep = \frac{I(H \pm d)}{(1.28H^2 + .75tH \pm 2dH + d^2 + t^2)^{3/2}} \qquad (7)$$

B. Maximum Scene Illumination Computations

The determination of maximum scene illumination values (Ep) on the flight line in the field of view of the camera starts with the basic equation for spherical flash illumination:

$$Ep = \frac{I \cos i}{D^2} \qquad (8)$$

Before proceeding further, it must be pointed out that two (2) different geometric relations can exist between the burst point and the field of view. If the point on the ground directly under the burst falls within the field of view of the camera, as shown in Fig. 2, then the factor D in equation (1) becomes the burst height h while the value of cos i becomes 1 since the angle of incidence i is zero. Since h is equal to H $\pm$ d, then equation (8) can be rewritten as:

$$Ep = \frac{I}{(H \pm d)^2} \qquad (9)$$

where H may be solved directly for any assumed value of Ep by rewriting the equation as:

$$H = \sqrt{\frac{I}{Ep}} - (\pm d) \qquad (10)$$

Since the burst trail distance factor t does not appear in equation (10), and since the effect of changes in aircraft speed on the drop distance is negligible, that portion of the maximum flight line scene illumination lines based on equation (10) is essentially a straight, vertical line. However, under certain combinations of low flight altitudes and/or high aircraft speeds, the point on the ground directly under the burst will fall to the rear of the field of view and the maximum flight line scene illumination will occur on the rear edge of the field of view. The slant range D will be greater than the burst height and the angle of incidence will no longer be equal to zero. To solve for maximum values of Ep under these conditions, requires the development of an equation similar to that which was developed for minimum values of Ep. From the geometry of the camera field of view and burst point shown in Fig. 3, the (D^2) factor of the rewritten basic illumination equation (equation (2) in Sec. A), can be related to H, t, and d in the following manner.

$$D^2 = h^2 + R^2 \qquad (11)$$

$$\text{and} \quad h^2 = (H \pm d)^2 \qquad (12)$$

$$\text{and} \quad R^2 = (t - H \tan \theta)^2 \qquad (13)$$

Substituting equations (12) and (13) in equation (11) gives:

$$D^2=(H\pm d)^2+(t-H\tan\theta)^2 \qquad (14)$$

which, after expanding and collecting terms becomes:

$$D^2=(1+\tan\theta^2)H^2\pm 2dH-2\tan\theta\, tH+d^2+t^2$$

Substituting the numerical value of tan θ = .375 for the 41° angular coverage of the K-47 lens in the preceeding equation gives:

$$D^2=1.14H^2-.75tH\pm 2dH+d^2+t^2 \qquad (15)$$

Substituting the value of D^2 from equation (8) in equation (2) of Section A. gives the following equation for the value of Ep in terms of I, H, t, and d:

$$Ep=\frac{I(H\pm d)}{(1.14H^2-.75tH\pm 2dH+d^2+t^2)^{3/2}} \qquad (16)$$

In order to establish the conditions under which equation (16) applies in the calculation of maximum scene illumination values, it is necessary to determine the geometric relations that exist when the nadir point of the burst falls on the rear edge of the field of view of the camera. From equation (14) it can be seen that when the term (t-H tan θ) becomes zero, the slant range D becomes equal to the burst height ($H\pm d$) indicating that the nadir point is on the rear edge of the field of view. By setting

$$t-H\tan\theta=0$$

and substituting the numerical value of tan θ = .375 and solving for H gives:

$$H=\frac{t}{.375} \qquad (17)$$

To use the above equation, it is necessary to assume an arbitrary airspeed, find the corresponding trail distance from the ballistic curves, substitute this value for t and solve for H. The value of H will represent the minimum altitude at the assumed airspeed which will keep the burst nadir point within the field of view and permit the use of equation (10) for plotting maximum scene illumination lines. For small distances of the burst nadir point to the rear of the field of view of the camera (10% or less of the burst height), the effects on computed values of using equation (10) when equation (16) should apply, are negligible. It is considered convenient to establish the position of the burst nadir point relative to the field of view for purposes of plotting scene illumination lines and in predicting whether a particular. combination of flight altitude and airspeed will result in severe burst reflection, especially over water. Using equation (17), a line can be plotted that contains all combinations of flight altitude and airspeed which put the burst nadir point on the rear edge of the field of view. Such a line is shown in the operational parameter plots of Figs. 1 to 8.

It should be noted that there is a definite similarity between equations (7) and (16) and that they share the common problem of not yielding to a simple method of factoring out the quantity H. In order to plot lines of constant illumination having specific values of Ep, it was found expedient to plot calculated values of Ep against substituted values of H in equations (7) and (16) using the ballistic coordinates t and d that corresponded to assumed specific aircraft speeds. Three (3) separate curves relating Ep to H were plotted for aircraft speeds of 200, 350 and 500 knots so that three (3) specific combinations of altitude and airspeed would be available for plotting each of the constant Ep lines. The curves defined by equations (7) and (16) are generally hyperbolic in form and if the plots are continued into the extreme low altitude and/or high airspeed area, the curves will go through a maximum Ep point of inflection due to the effect of the increasing angle of incidence. Although most of the constant Ep lines do not extend into the area of curve inflection, this condition does explain why some operational parameter plots do not contain the 2.1, 2.4 and 2.7 maximum Ep lines.

C. Maximum to Minimum Scene Illumination Ratio

The method of computing maximum to minimum scene illumination ratio limits starts with the basic spherical burst illumination equation:

$$Ep = \frac{I \cos i}{D^2} \qquad (18)$$

This equation can be rewritten, according to the geometry of Figs. 1 & 2, as:

$$Ep_{(min.)} = \frac{I(H \pm d)}{D^3_{min.}} \qquad (19)$$

$$Ep_{(max.)} = \frac{I(H \pm d)}{D^3_{max.}} \qquad (20)$$

Since R is the ratio of scene illumination by definition, then

$$R = \frac{Ep_{(max.)}}{Ep_{(min)}} \qquad (21)$$

Substituting equation (19) and (20) in equation (21) gives:

$$R = \frac{I(H \pm d)}{D^3 max.} \times \frac{D^3 min.}{I(H \pm d)}$$

which reduces to:

$$R = \frac{D^3(min.)}{D^3(max.)} \qquad (22)$$

Since expressions for D^2 (maximum) and D^2 (minimum) have been developed in Sections A and B, it is more convenient to make substitutions if equation (22) is expressed in terms of D^2 by rewriting it as follows:

$$R = \left(\frac{D^2 min.}{D^2 max.}\right)^{\frac{3}{2}} \qquad (23)$$

Substituting for D^2 (minimum), the value found in equation (6) of Section A and for D^2 (maximum), its equivalent of $(H \pm d)^2$ for conditions where the point directly under the burst falls within the field of view in equation (23) gives the following expression:

$$R = \left(\frac{1.28H^2 + .75tH \pm 2dH + t^2 + d^2}{H^2 \pm 2dH + d^2}\right)^{\frac{3}{2}} \qquad (24)$$

By substituting in equation (23), the value for D^2 (maximum) found in equation (15) of Section B for conditions where the point directly under the burst point falls outside the field of view gives the following expression:

$$R = \left(\frac{1.28H^2 + .75tH \pm 2dH + t^2 + d^2}{1.14H^2 - .75tH \pm 2dH + t^2 + d^2} \right)^{\frac{3}{2}} \qquad (25)$$

From equations (24) and (25), values of illumination ratio R can be solved for any assumed combinations of flight altitude H and airspeed (through corresponding trail and drop values). For the purposes of plotting specific ratio lines on the operational parameter plots, it was more convenient to express equations (24) and (25) in terms of H as the dependent variable as follows:

First raise both sides of equation (24) to the 2/3 power and clear of fractions, which gives:

$$R^{\frac{2}{3}}H^2 \pm 2R^{\frac{2}{3}}dH + R^{\frac{2}{3}}d^2 = 1.28H^2 + .75tH \pm 2dH + t^2 + d^2$$

collecting terms and equating to zero gives:

$$0 = (R^{\frac{2}{3}} - 1.28)H^2 - [.75t \pm (R^{\frac{2}{3}} - 1)2d]H - [t^2 - (R^{\frac{2}{3}} - 1)d^2]$$

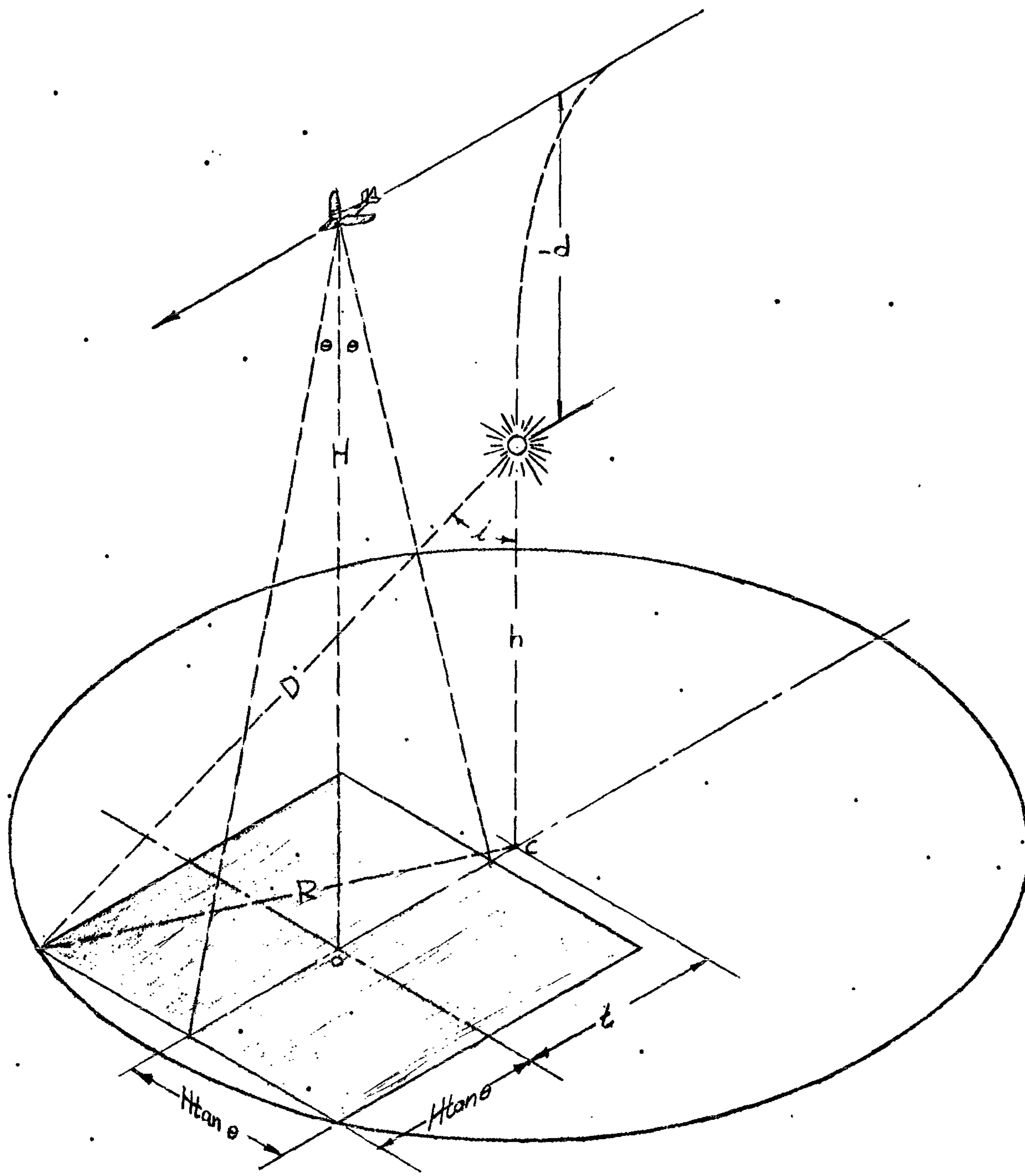
using the general formula for quadratic equations gives:

$$H = \frac{[.75t \pm (R^{\frac{2}{3}} - 1)2d] \pm \sqrt{[.75t \pm (R^{\frac{2}{3}} - 1)2d]^2 + 4(R^{\frac{2}{3}} - 1.28)[t^2 - (R^{\frac{2}{3}} - 1)d^2]}}{2(R^{\frac{2}{3}} - 1.28)} \qquad (26)$$

in a similar manner equation (25) can be expressed in terms of H as follows:

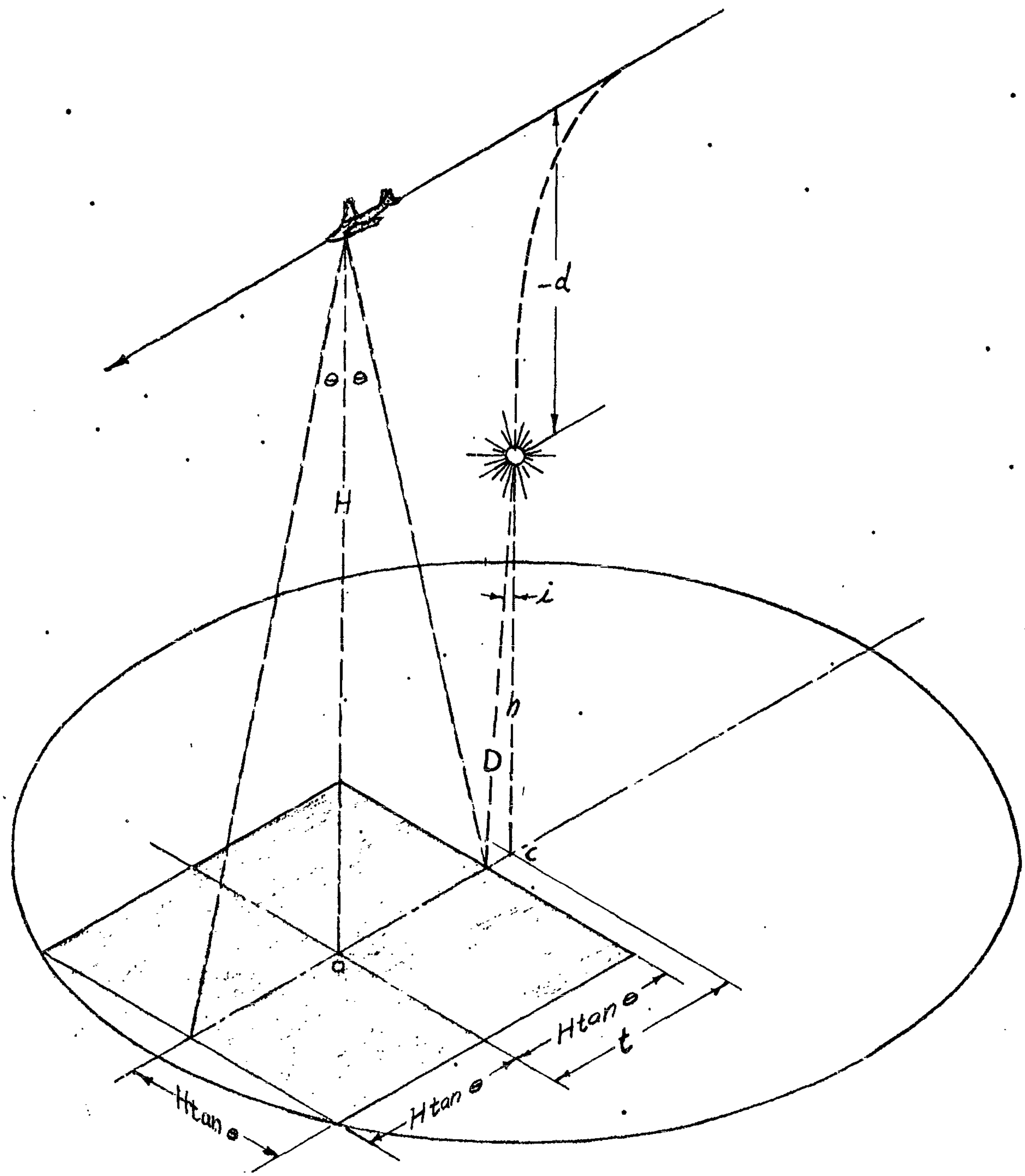
$$\frac{[(R^{\frac{2}{3}} + 1).75t \pm (R^{\frac{2}{3}} - 1)2d] \pm \sqrt{[(R^{\frac{2}{3}} + 1).75t \pm (R^{\frac{2}{3}} - 1)2d]^2 - 4(1.14R^{\frac{2}{3}} - 1.28)(R^{\frac{2}{3}} - 1)(d^2 + t^2)}}{2(1.14R^{\frac{2}{3}} - 1.28)} \qquad (27)$$

It should be noted that the double signs before the radical sign in equations (26) and (27) are the result of the quadratic equations formula and bear no relationship to upward or downward cartridge ejection. Under certain conditions of assumed airspeed and illumination ratio, the quantity under the radical sign will become negative, indicating that the assumed ratio cannot exist at this airspeed regardless of flight altitude. This condition explains the absence of the 3 to 1 and 2½ to 1 ratio lines on some operational parameter plots.



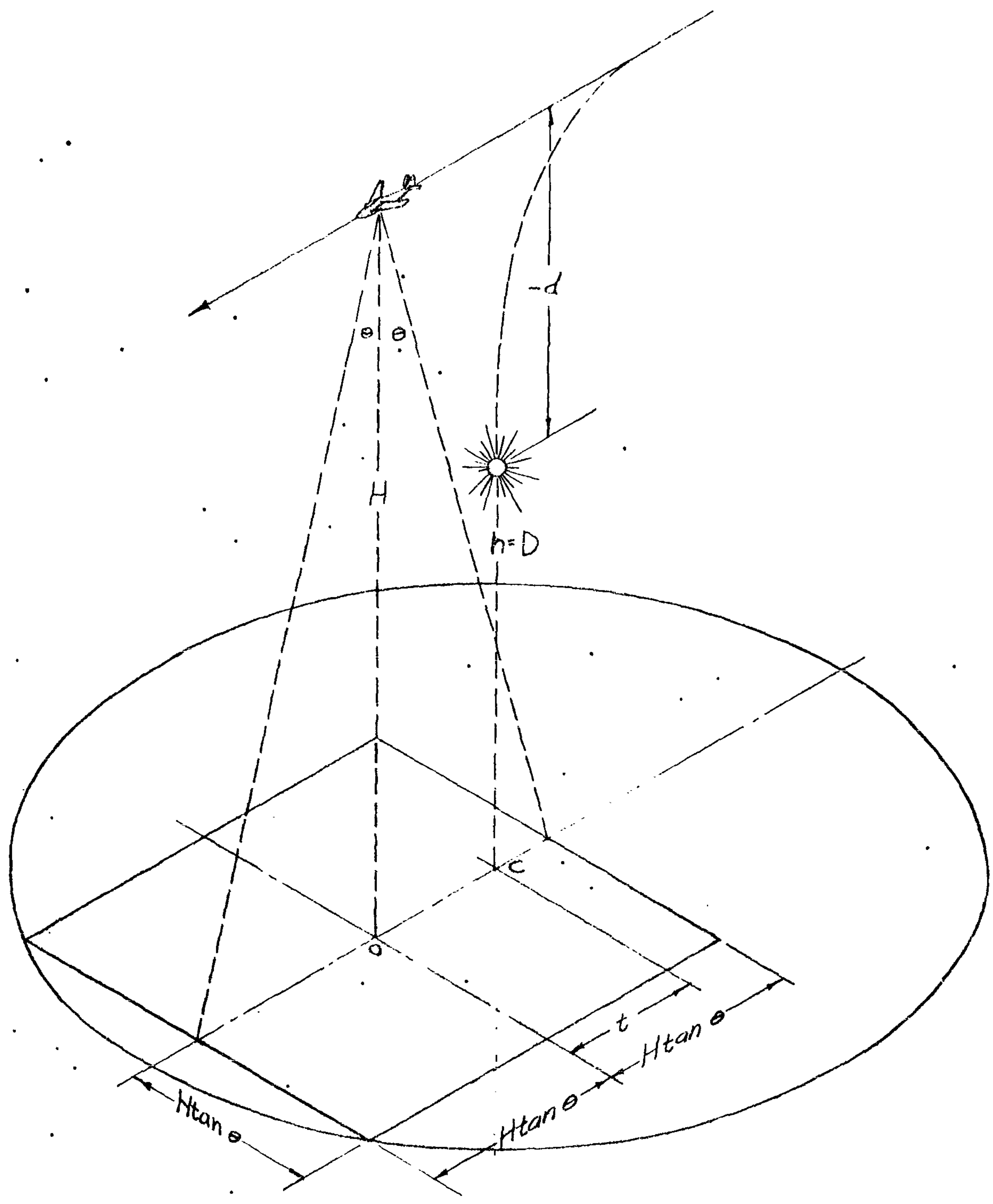
GEOMETRY OF FORWARD CORNER MINIMUM SCENE ILLUMINATION

APPENDIX I FIGURE 1



GEOMETRY OF FLIGHT LINE MAXIMUM SCENE ILLUMINATION
BURST POINT NADIR OUTSIDE FIELD OF VIEW

APPENDIX I FIGURE 2



GEOMETRY OF FLIGHT LINE MAXIMUM SCENE ILLUMINATION
BURST POINT NADIR INSIDE FIELD OF VIEW

APPENDIX I FIGURE 3

APPENDIX II

A. Brief Explanation of the Meaning and Use of Operational Parameter Charts for the K-47 Night Camera.

Referring to Graph No. 1 as a typical operational parameter chart, it will be noted that the near vertical lines starting on the right hand side of the graph and increasing in numerical value towards the left are lines of constant, forward corner scene illumination. They represent plots of all combinations of air speeds and altitudes which will produce the constant numerical values of forward corner illumination shown at the lower end of the lines. Thus, for any co-ordinate point consisting of a selected air speed and altitude value falling within this grid pattern it is possible to approximate the actual scene illumination in foot-candle-seconds occuring at the forward corner of the field of view of the camera for the selected flight conditions. These grid lines of constant forward corner scene illumination were plotted for an arbitrary range of .03 to .27 foot-candle-seconds (fcs). Although these lines could have been continued further toward the left side of the graph, since they represent the minimum acceptable illumination level for a particular lens-shutter-film combination under average conditions, speed and altitude co-ordinate points falling to the left of the grid pattern would indicate more than adequate illumination and the numerical values would be unimportant. The dotted lines represent minimum forward corner scene illumination values for specific shutter modes of the K-47 camera.

The vertical lines starting on the left hand side of the graph and decreasing in numerical value towards the right are lines of constant maximum illumination on the flight line within the field of view of the camera. As in the case of the forward corner illumination values, the numerical values of the maximum scene illumination lines bear no direct relationship with any base scale on the graph. Although, the lines appear to be based on a continuation of the same numerical scale that applies to the forward corner scene illumination values, the scales of the maximum and minimum scene illumination grid patterns are entirely unrelated since different equations were used in their computation. The grid lines of maximum flight line illumination were plotted for an arbitrary range of 2.7 to .9 fcs for the express purpose of indicating an operational area where over exposure might occur. It will be noted that this range of numerical values is just 10 times the range on the minimum scene illumination grid that brackets the three shutter mode values indicated by dotted lines. This range relationship is based on the assumption that a ten fold increase in scene illumination over that value previously established as a minimum for a particular lens-shutter-film combination is all that can be tolerated without controlling exposure at the camera. It will be shown subsequently that these extreme changes in scene illumination never occur within the field of view of the camera for any selected air speed and altitude covered by the graphs. They can only result from excessive altitude changes during a night photographic mission and can be controlled to a certain extent by shutter mode changes.

The maximum to minimum scene illumination ratios that are far more important are those that are indicated by the diagonal solid lines cutting across the upper left hand corner of the graphs. These lines show the scene illumination change within the field of view of a particular photograph under the conditions of air speed and altitude falling on the line. These changes affect the negative density within a given photograph and can cause loss of image detail which can only be recovered by special printing techniques. A 2 to 1 ratio is considered a desirable limit although a ratio of 3 to 1 can be tolerated.

The diagonal $t = H \tan \theta$ line denotes those combinations of maximum air speeds and minimum altitudes which place the nadir point of the flash burst on the rear edge of the field of view of the camera. Any increase in air speed or reduction in altitude beyond the combinations falling on this line would place the nadir point outside the field of view of the camera. This consideration might be important when flying over highly reflective terrain such as marshes or open water.

B. Use of Operational Parameter Charts for any 41° Angular Coverage Lens and Film Combination.

The charts developed in this report can be adapted to any vertically mounted camera employing a 41° angular coverage lens when used with either upward or downward ejected M-112 and M-123 flash cartridges. The procedure requires only one night photographic flight test to determine the minimum scene illumination requirements which will replace those shown on the charts as dotted lines. After selecting either the M-112 or the M-123 flash cartridge with a particular fuse delay using either upward or downward cartridge ejection, perform a series of night aerial photographic runs in the following manner. Using any one of the three basic shutter modes shown in the charts and maintaining constant air speed, make a series of exposures at various altitudes in increments of about 500 ft. starting at a 1,000 ft. minimum for the M-112 and a 2,000 ft. minimum for the M-123 cartridge. Process film according to the standard procedure for night photography and analyze the negatives to determine the highest altitude for which a negative having adequate image density in the forward corners is obtained. Mark the position of altitude and air speed on the particular operational parameter graph corresponding to the cartridge, fuse delay and launching orientation used in the test. Since the slopes of any two adjacent minimum scene illumination lines are nearly the same, it is only necessary to draw a line through the point previously marked on the graph, making it parallel to the closest minimum scene illumination line. The acceptable minimum scene illumination value in foot-candle-seconds obtained for a particular shutter mode with any one of the given charts is applicable to the other charts included in this report and eliminates the performance of any additional flight tests. Using the minimum scene illumination determination made with a single flight test, these lines can then be drawn on the other charts to obtain operational guide lines for any selected combination of cartridge types, fuse delays and vertically upward or downward ejector orientation. In order to obtain minimum scene illumination lines for shutter modes other than the one used in the flight tests, the previously established light utilization percentages for the various shutter modes should be used in accordance with the following formula:

$$E_p \text{ (for any selected shutter mode)} = \frac{\text{light utilization percentage for flight test shutter mode.}}{\text{light utilization percentage for selected shutter mode.}}$$

The light utilization percentages for the three shutter modes shown on the graphs have been established at 100% for recycle open-full flash, 65% for recycle open-synchronous closure at 1/100 second and 50% for full synchronous at 1/100 second.

APPENDIX III

WIRING CHANGE FOR CONVERTING THE RECYCLE-OPEN SHUTTER MODE OF THE K-47 CAMERA SYSTEM FROM END OF SHUTTER WIND OPENING TO END OF FILM ADVANCE OPENING

The following wiring change is applicable to the Aerial Camera System, Type K-47, (T.O. 10A1-5-18-1) consisting of the type C-1 Flash Detector, the Type E-1 Shutter Speed Timer, the Type T-1 Shutter Speed Timer Control, the Type K-47 Camera, and the Type MA-10a Magazine. The basic purpose of the change is to improve the operation of the recycle-open shutter mode of the system by delaying the opening of the "A" shutter blade assembly, until the end of the film advance function of the magazine. The existing circuitry opens the "A" blades at the end of the shutter wind function of the camera and will permit ground lights or fires to image on the film during the time when it is not moving at IMC velocity. The wiring change is accomplished by removing the wire from Pin E of the AN3106-18-8S plug at the K-47 camera and rerouting and attaching it to Pin b of the AN3106-28-12S plug at the MA-10a magazine. The opposite end of this cable remains attached to the AN3106-18-8p plug at the E-1 Shutter Timer. It should be noted that this wiring change may require the fabrication of a new wiring harness between plugs AN3106-18-8S, AN3106-28-12S and AN3106-28-8P. It should also be noted that the wiring change will prevent use of a stationary film magazine in the recycle-open shutter mode. Other shutter modes are not affected by the wiring change.

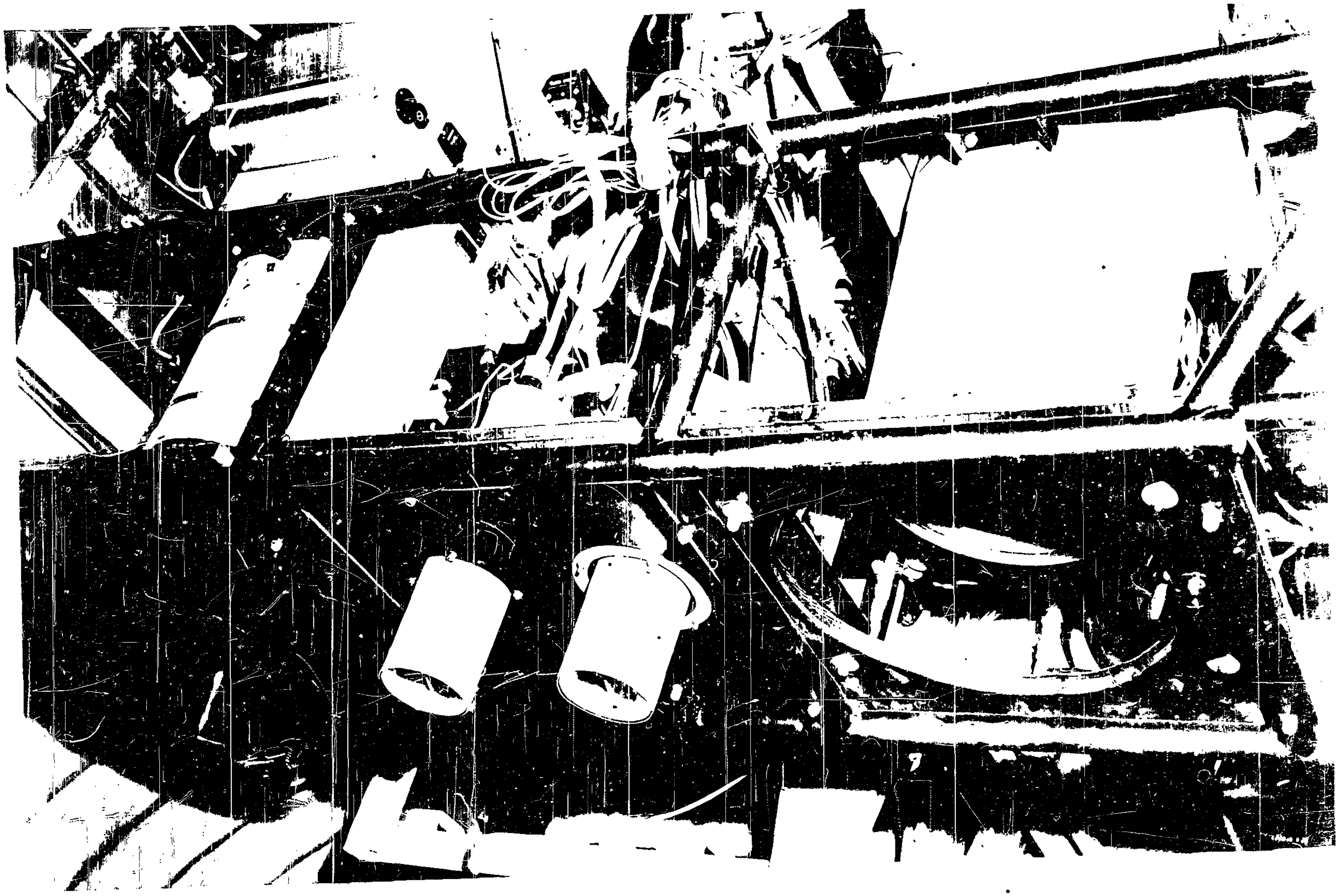


FIGURE 1 - K-47 CAMERA INSTALLATION IN BOMB BAY OF P2V AIRCRAFT #456.

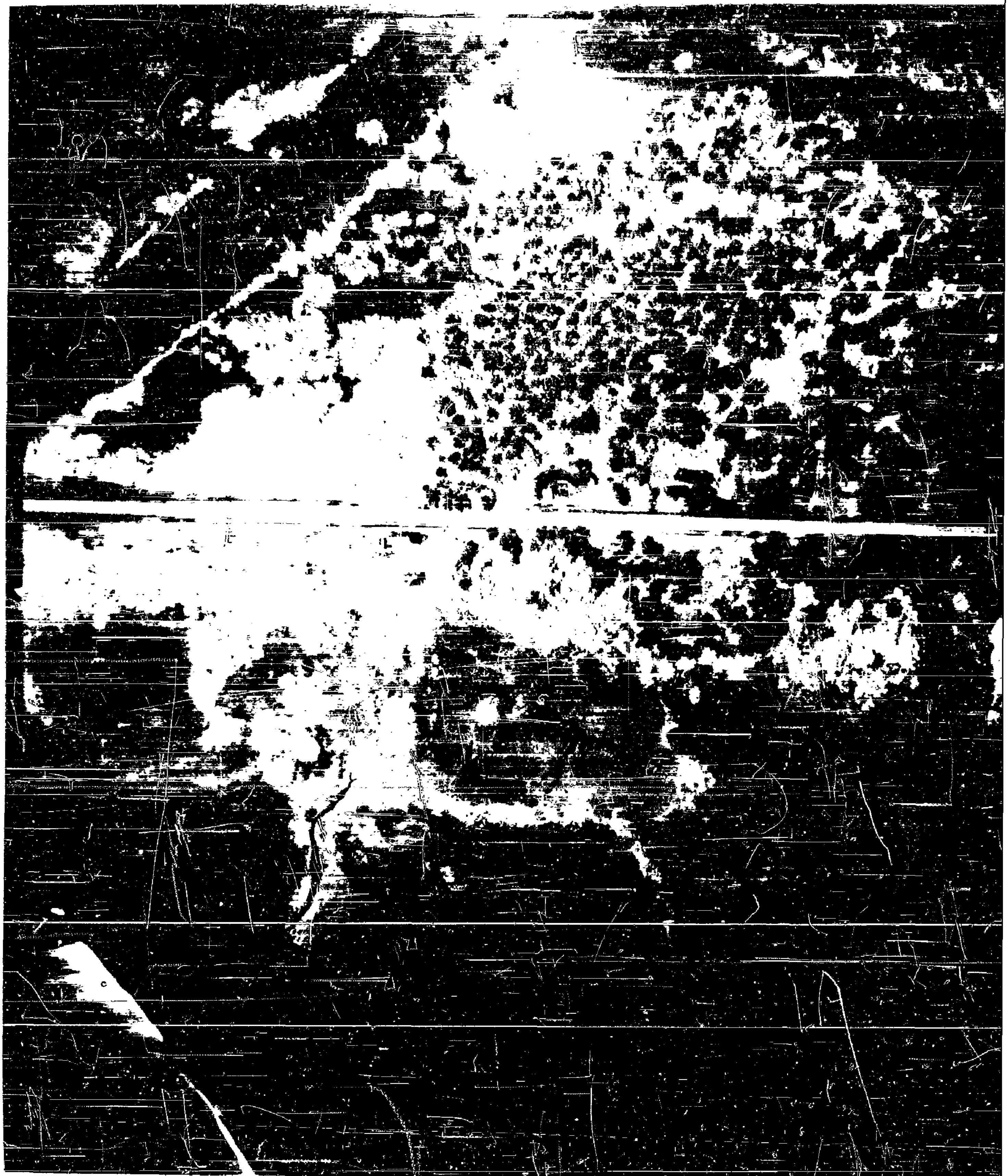


FIGURE 6. - SHOWING EFFECTS OF USING INFRARED FILM ON
IMAGE DETAIL

FIGURE 7. - SHOWING EFFECTS OF UPWARD EJECTION OF
M-112 FLASH CARTRIDGE ON IMAGE DETAIL

FIGURE 2. - SHOWING LENS FLARE RESULTING FROM SMALL TRAIL ANGLE BURST POSITION WITHOUT LENS SHADE

FIGURE 3. - SHOWING ABSENCE OF LENS FLARE WHEN USING LENS SHADE WITH SMALL TRAIL ANGLE BURST POSITION

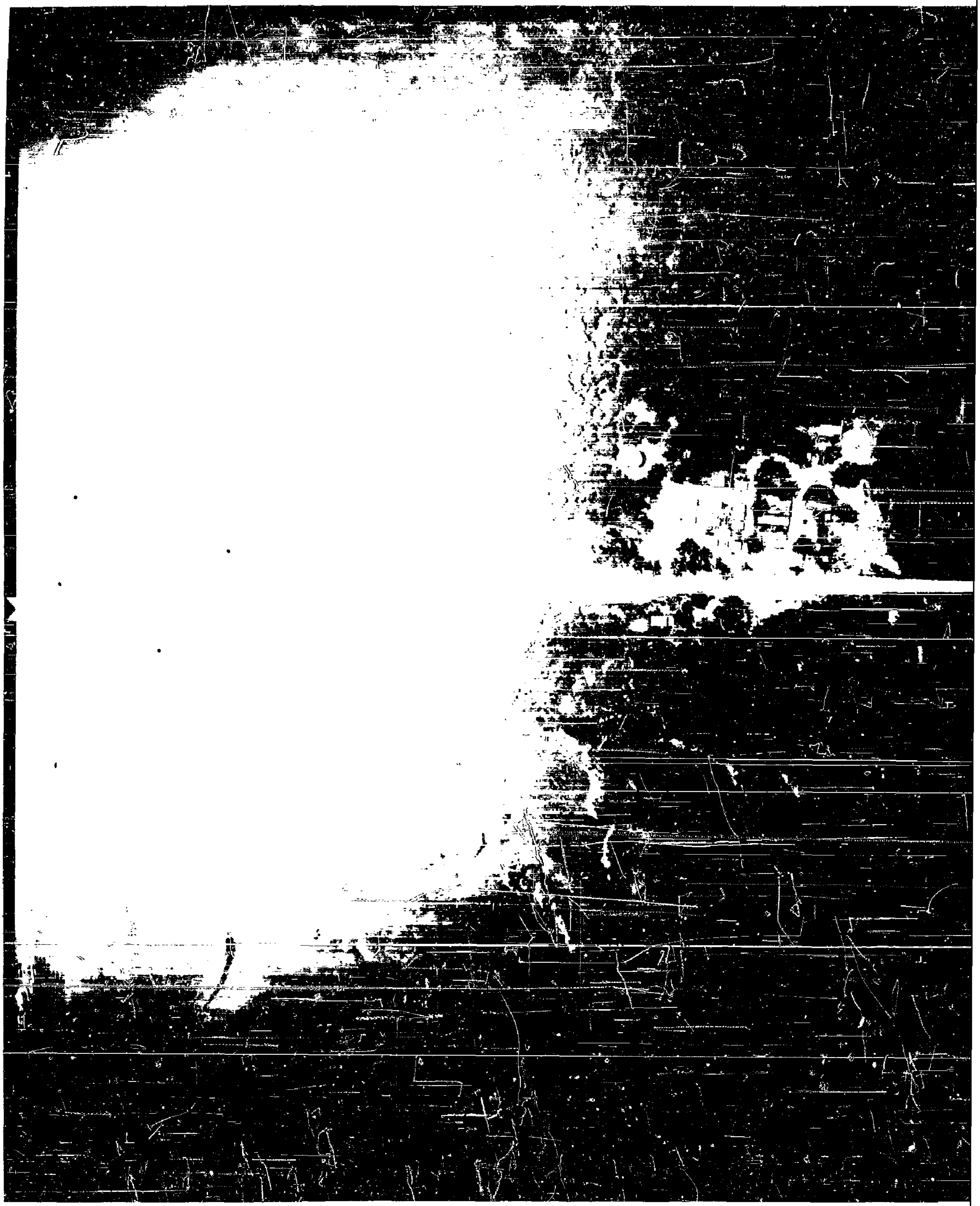


FIGURE 4. - SHOWING EFFECTS OF A SMALL TRAIL ANGLE BURST POSITION ON IMAGE DETAIL UNDER HAZE CONDITIONS

FIGURE 5. - SHOWING EFFECTS OF A LARGE TRAIL ANGLE BURST POSITION ON IMAGE DETAIL UNDER HAZE CONDITIONS

FIGURE 8. - SHOWING HIGHLY ACCEPTABLE PRINT QUALITY RESULTING FROM NORMAL DENSITY NEGATIVE MADE WITH UPWARD EJECTED M-123 CARTRIDGE AT 3000 FT.

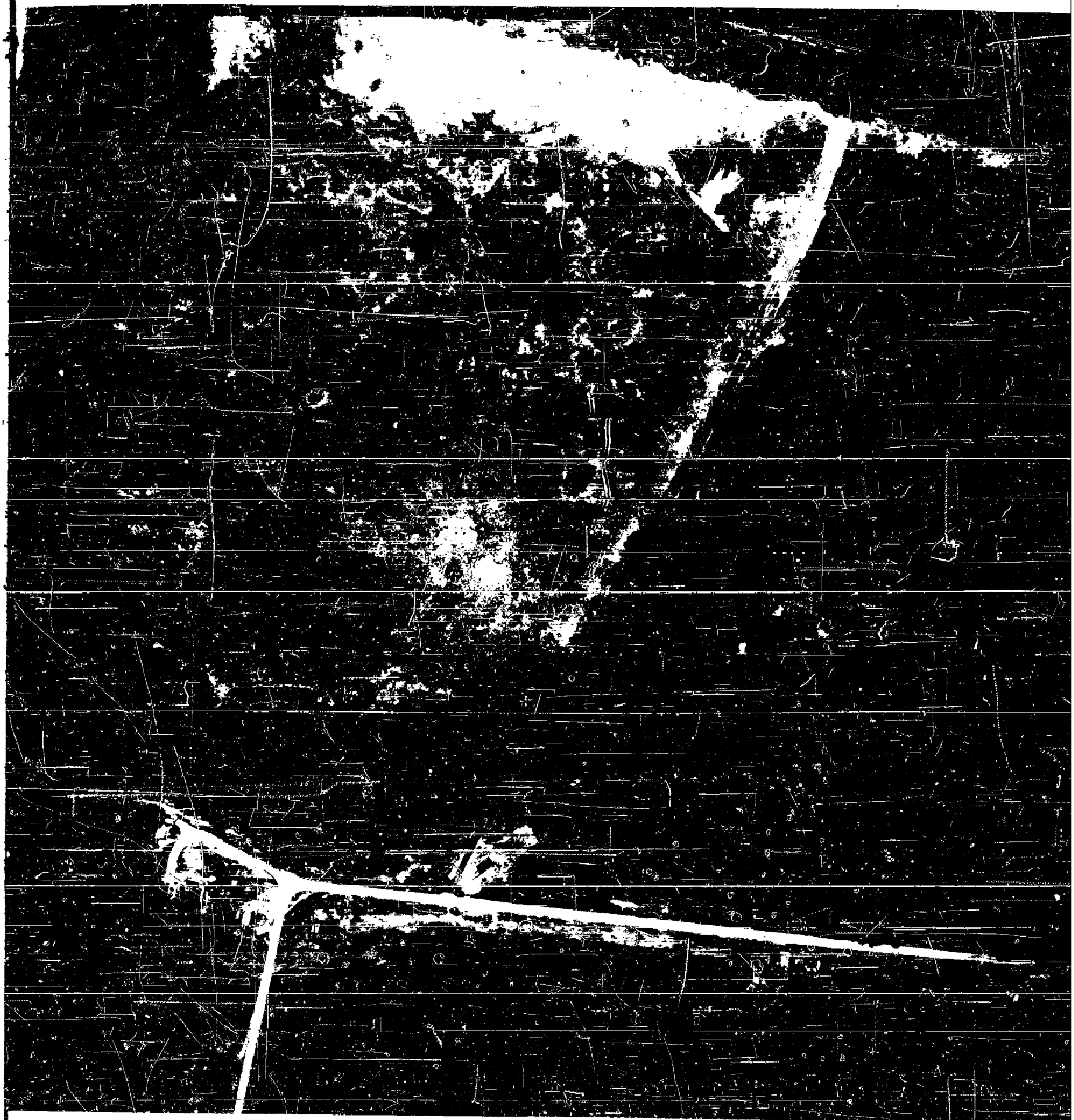


FIGURE 9. - SHOWING USABLE PRINT QUALITY RESULTING FROM THIN NEGATIVE MADE WITH UPWARD EJECTED M-123 CARTRIDGE AT 4000 FT.

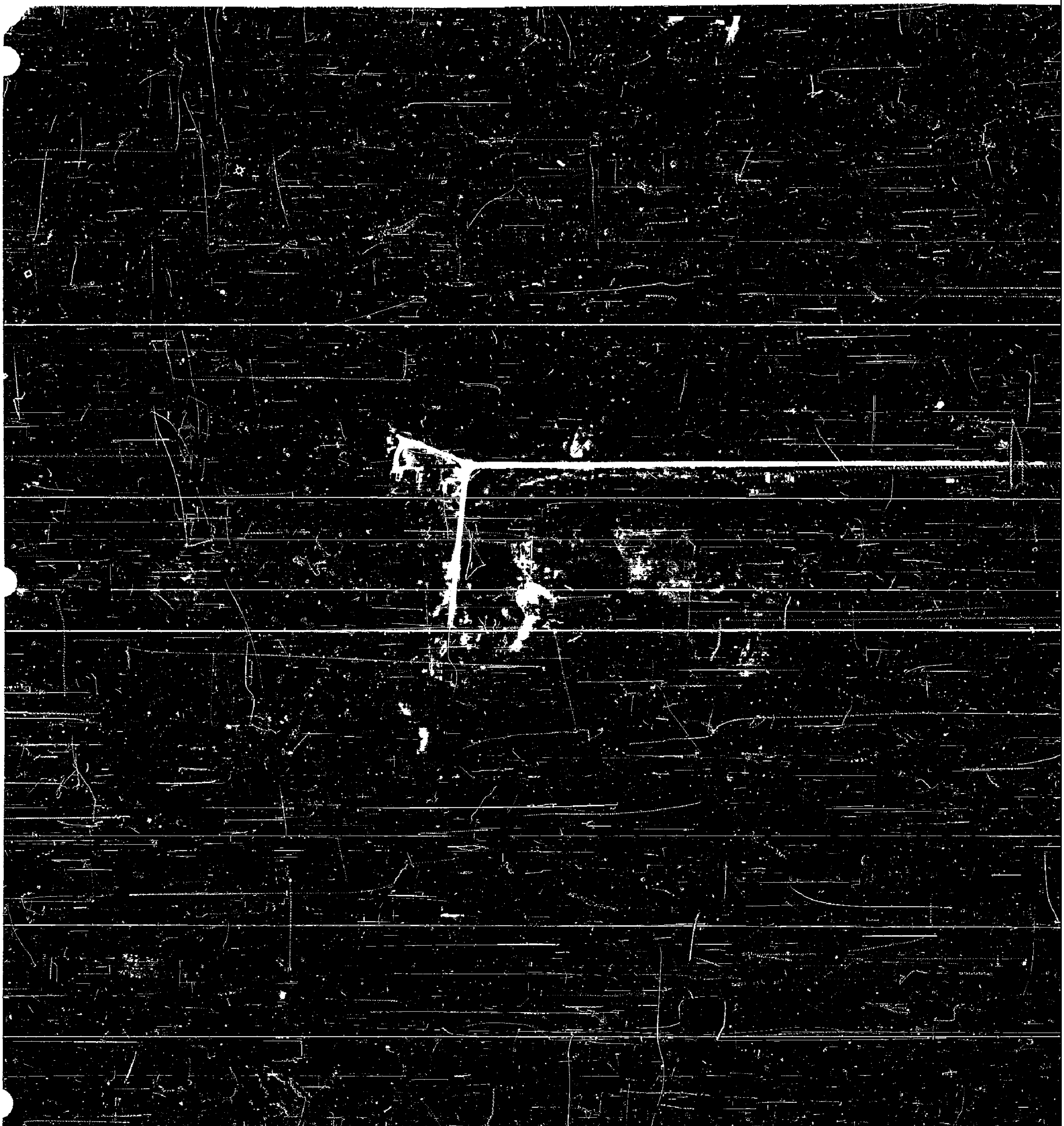
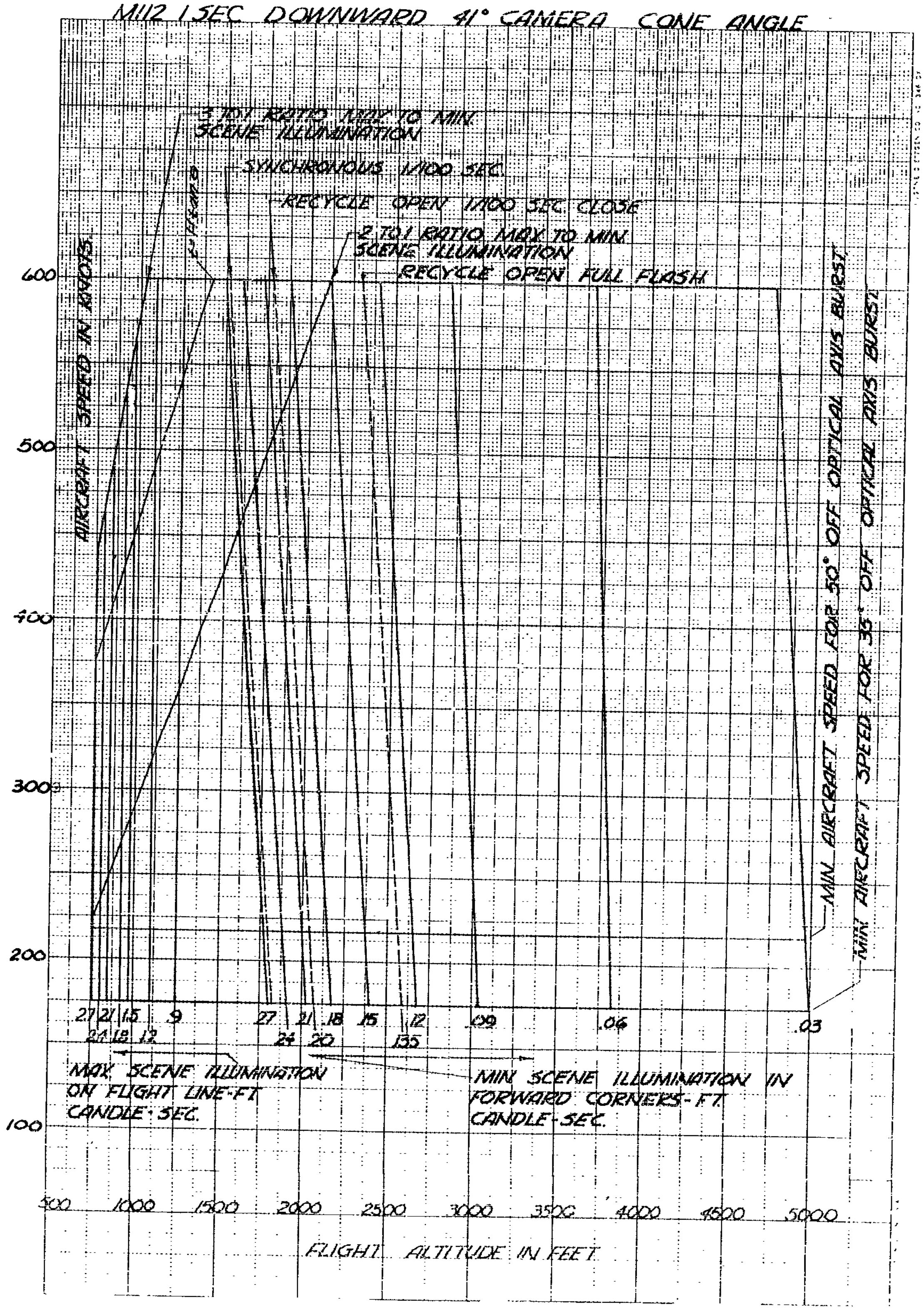


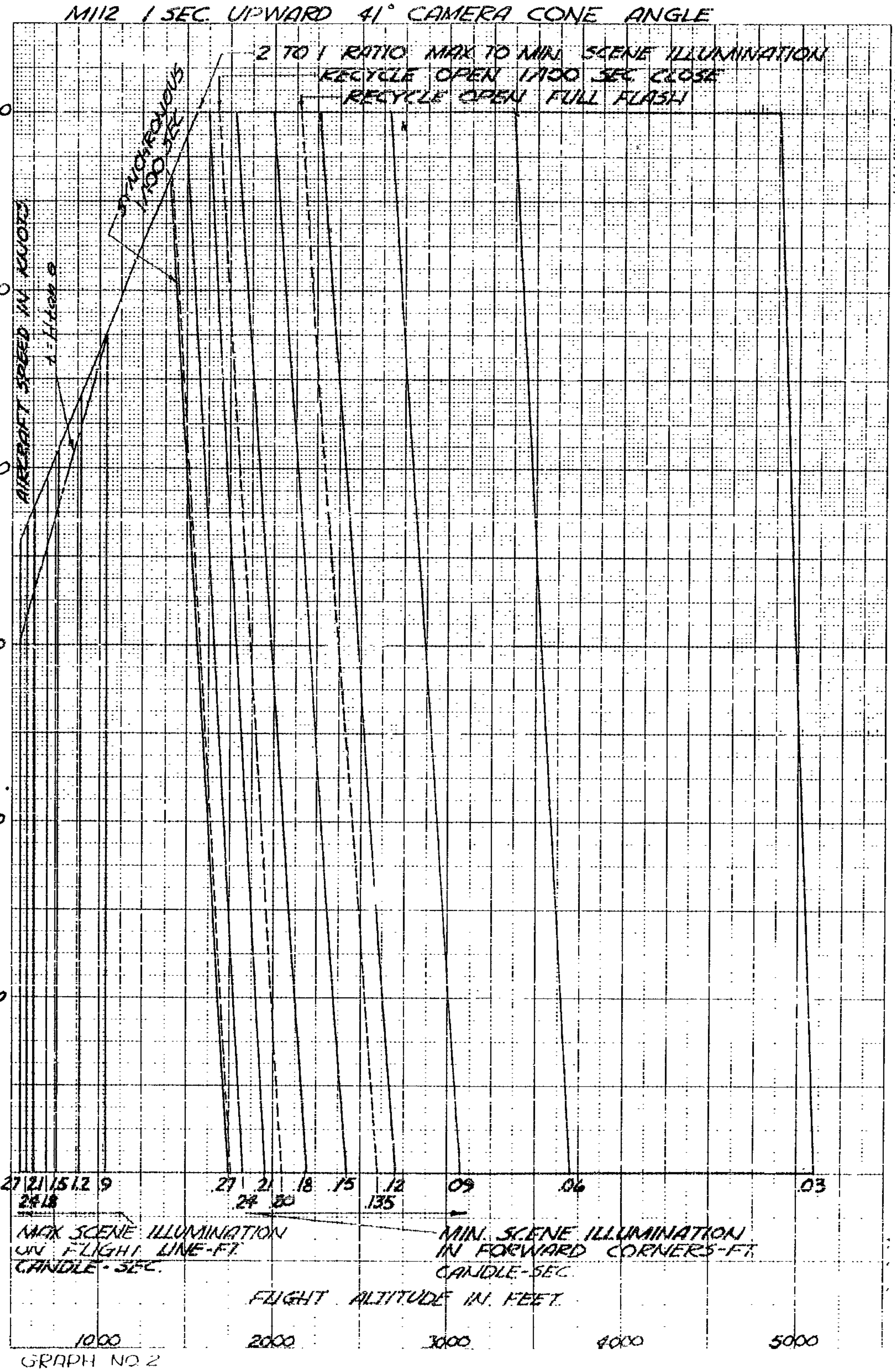
FIGURE 10. - SHOWING LIMITED INFORMATION CONTENT OF PRINT MADE WITH VERY THIN NEGATIVE USING UPWARD EJECTED M-123 CARTRIDGE AT 5000 FT.



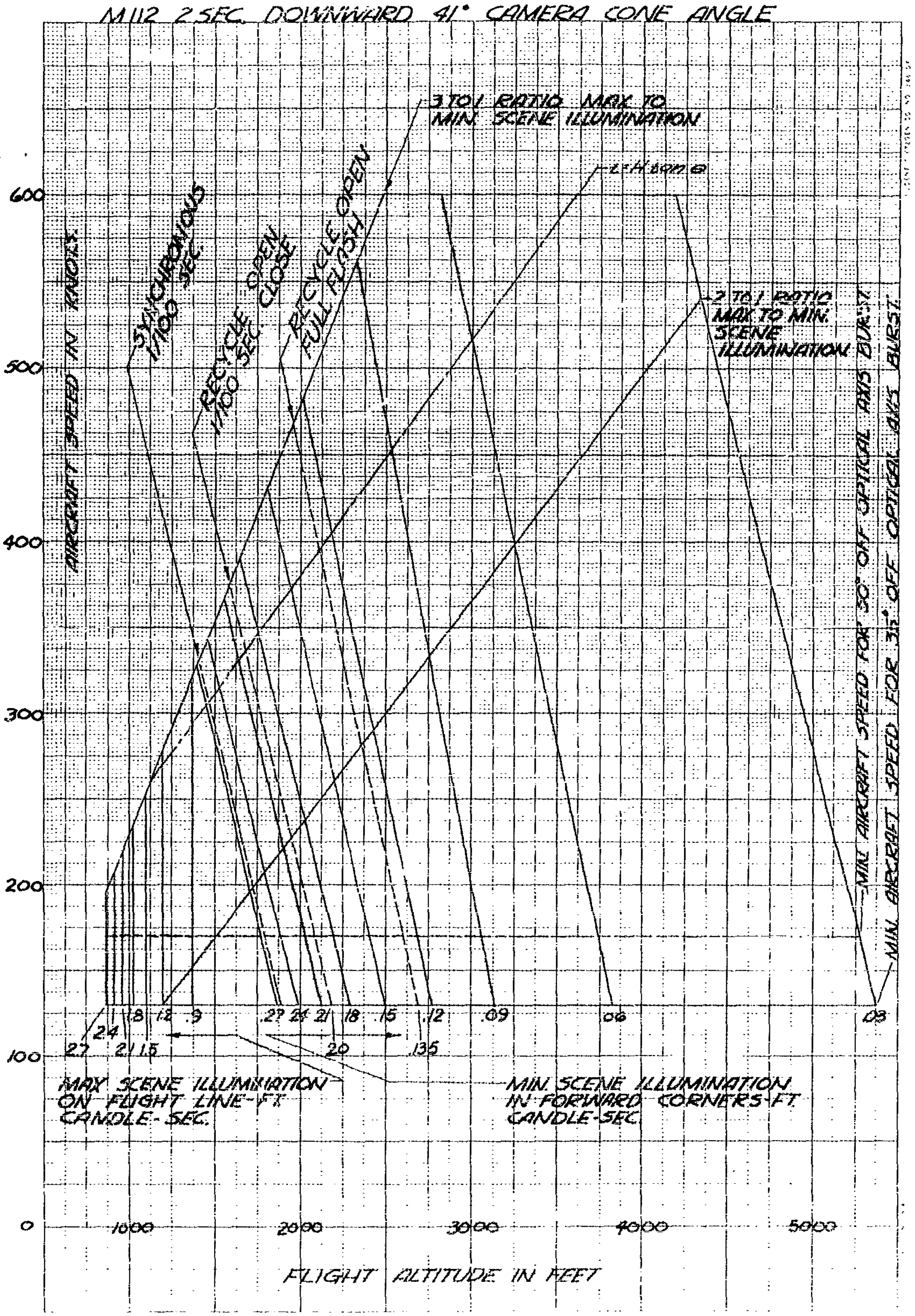
M112 1 SEC DOWNWARD 41° CAMERA CONE ANGLE
3 TO 1 RATIO MAX TO MIN SCENE ILLUMINATION
SYNCHRONOUS 1/100 SEC
RECYCLE OPEN 1/100 SEC CLOSE
2 TO 1 RATIO MAX TO MIN SCENE ILLUMINATION
RECYCLE OPEN FULL FLASH
AIRCRAFT SPEED IN KNOTS
600
500
400
300
200
100
27 21 15 9
24 18 12
27 21 18 15 12 .09 .06 .03
24 20 135
MAX SCENE ILLUMINATION ON FLIGHT LINE-FT CANDLE-SEC.
MIN SCENE ILLUMINATION IN FORWARD CORNERS-FT CANDLE-SEC.
MIN AIRCRAFT SPEED FOR 50° OFF OPTICAL AXIS BURST
MIN AIRCRAFT SPEED FOR 35° OFF OPTICAL AXIS BURST
500 1000 1500 2000 2500 3000 3500 4000 4500 5000
FLIGHT ALTITUDE IN FEET

GRAPH NO 1

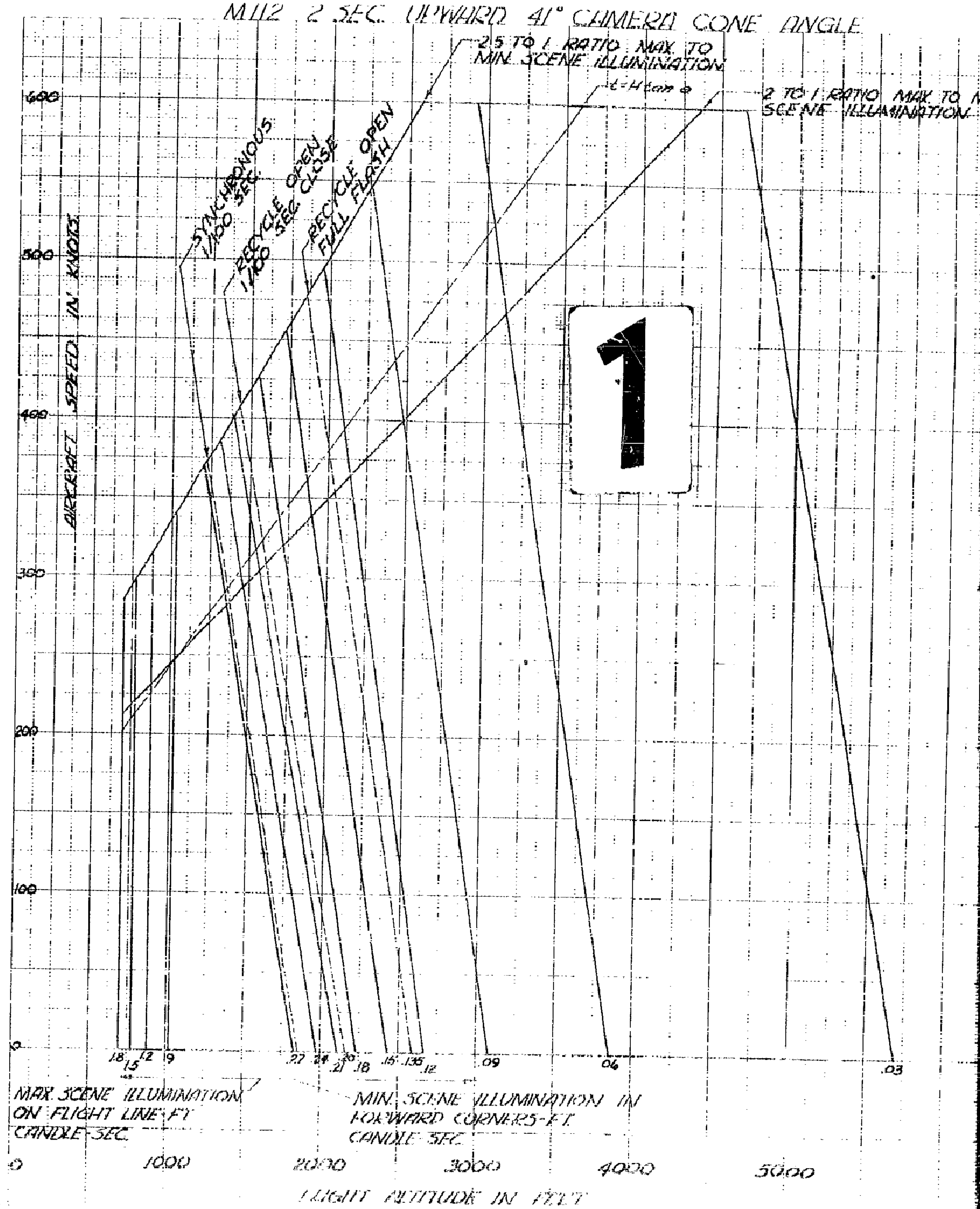
M112 1 SEC. UPWARD 41° CAMERA CONE ANGLE

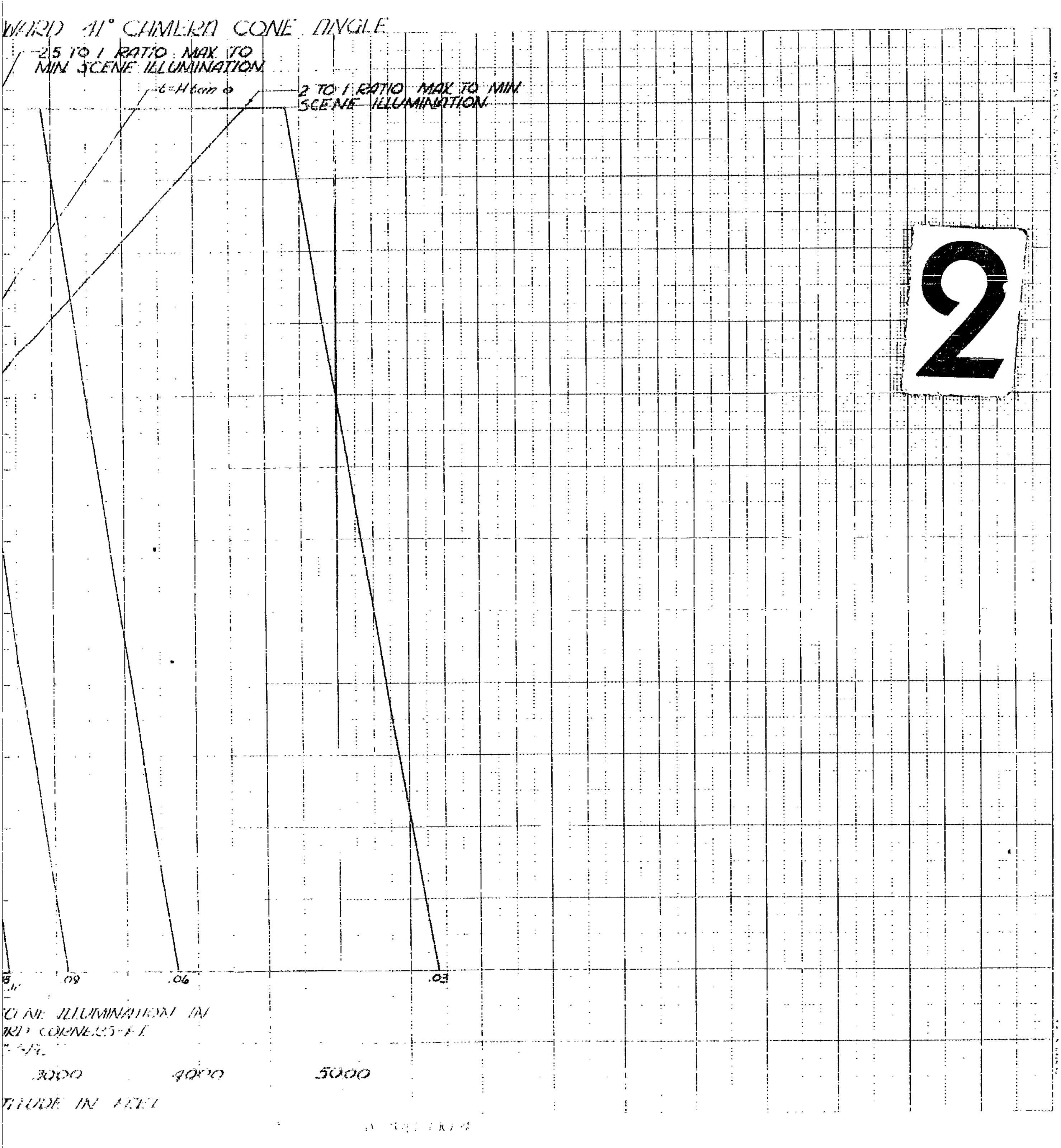


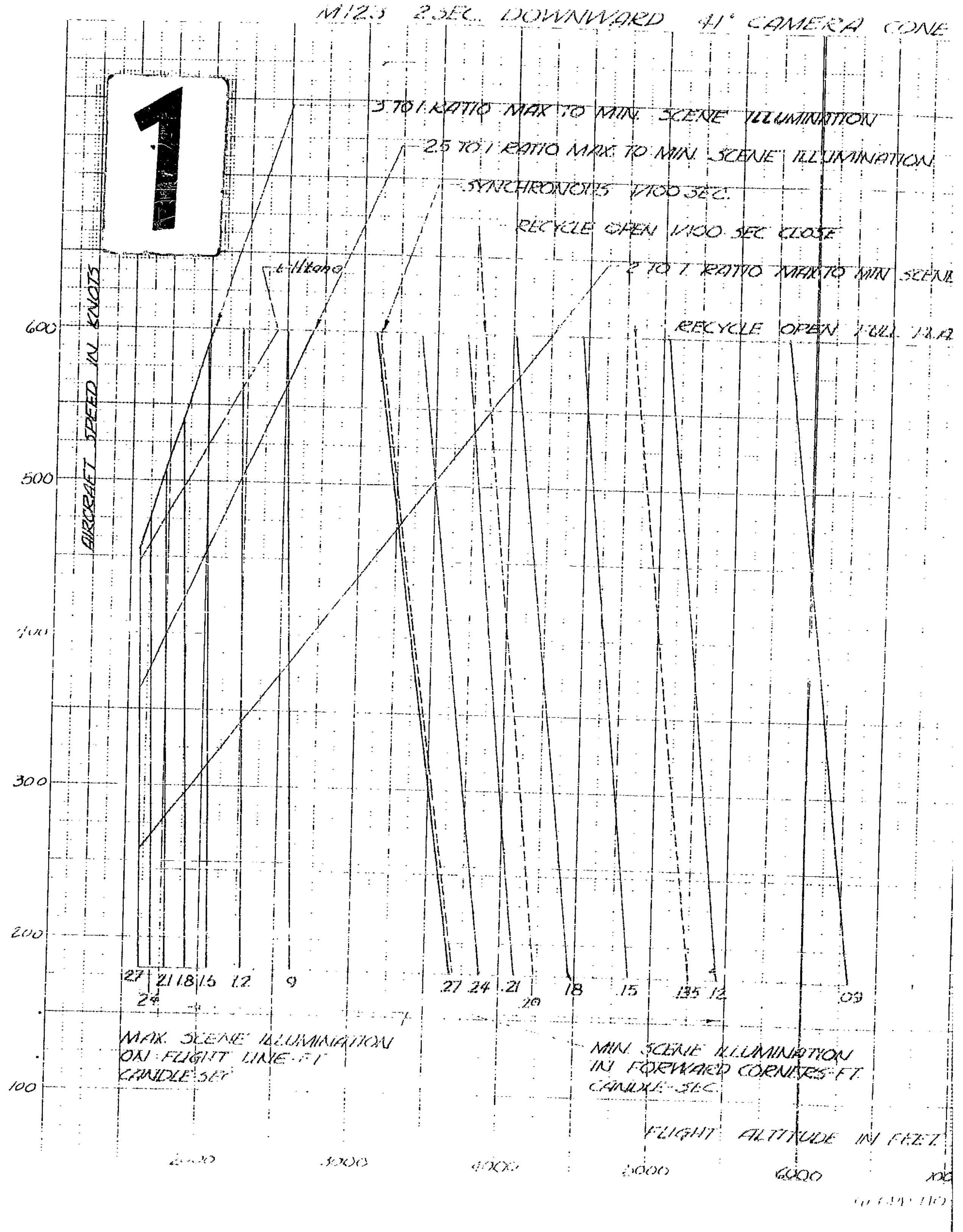
GRAPH NO 2


M112 2 SEC. DOWNWARD 41° CAMERA CONE ANGLE
3 TO 1 RATIO MAX TO MIN. SCENE ILLUMINATION
2 TO 1 RATIO MAX TO MIN. SCENE ILLUMINATION
SYNCHRONOUS 1/100 SEC
RECYCLE OPEN 1/100 SEC CLOSE
RECYCLE OPEN FULL FLASH
AIRCRAFT SPEED IN KNOTS
MIN. AIRCRAFT SPEED FOR 30° OFF OPTICAL AXIS BURST
MIN. AIRCRAFT SPEED FOR 35° OFF OPTICAL AXIS BURST
MAX SCENE ILLUMINATION ON FLIGHT LINE-FT CANDLE-SEC.
MIN. SCENE ILLUMINATION IN FORWARD CORNERS-FT CANDLE-SEC.
FLIGHT ALTITUDE IN FEET
0
100
200
300
400
500
600
1000
2000
3000
4000
5000
.27
.24
.21
.18
.15
.12
.9
.27
.24
.21
.18
.15
.12
.09
.06
.03
.20
.135

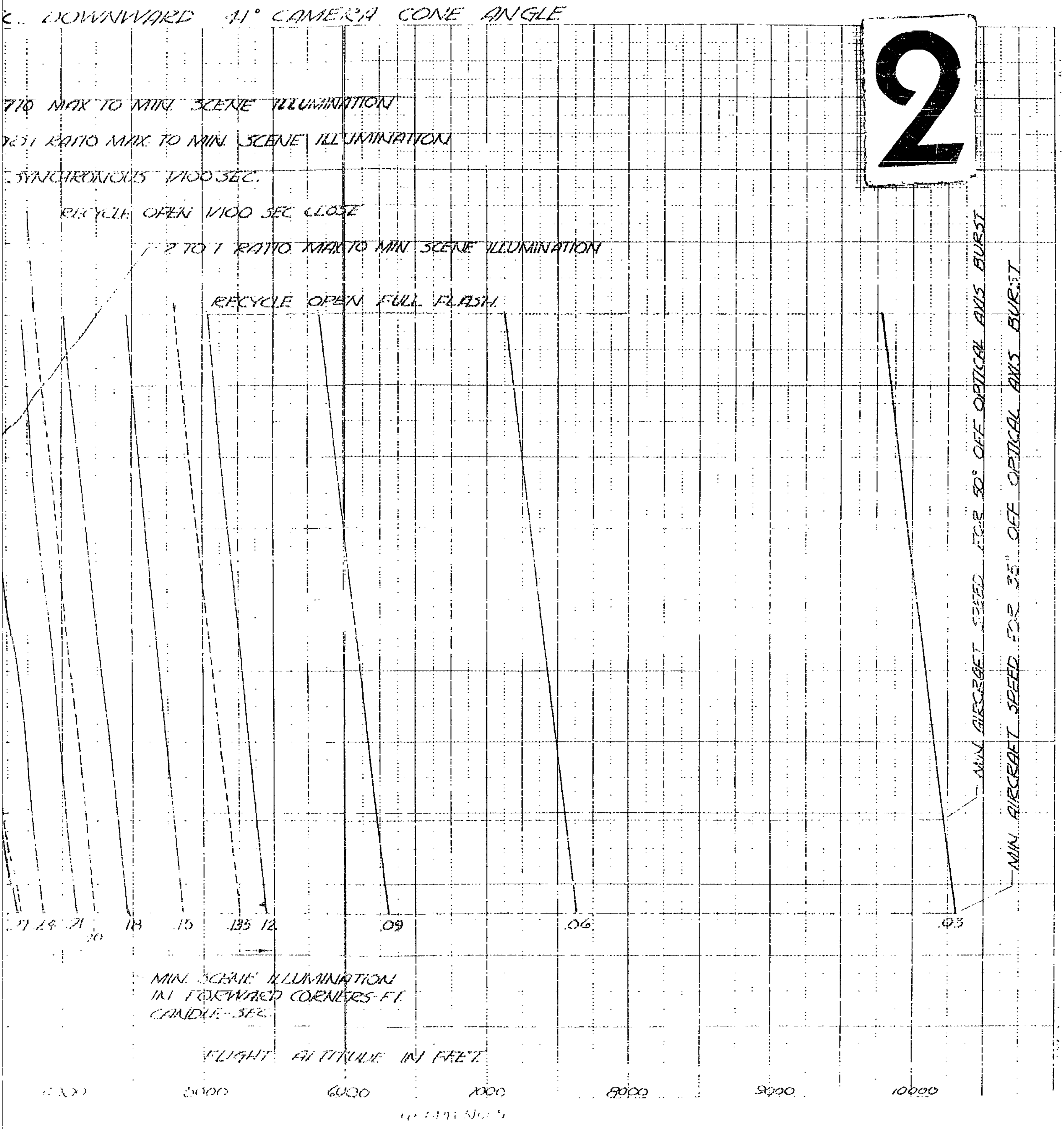
GRAPH NO.3


M112 2 SEC UPWARD 41° CAMERA CONE ANGLE
2.5 TO 1 RATIO MAX TO MIN SCENE ILLUMINATION
2 TO 1 RATIO MAX TO MIN SCENE ILLUMINATION
SYNCHRONOUS 1/100 SEC.
RECYCLE OPEN 1/100 SEC CLOSE
RECYCLE OPEN FULL FLASH
AIRCRAFT SPEED IN KNOTS
600
500
400
300
200
100
0
.18
.15
.12
.9
.27
.24
.21
.18
.15
.135
.12
.09
.06
.03
MAX SCENE ILLUMINATION ON FLIGHT LINE FT CANDLE-SEC
MIN SCENE ILLUMINATION IN FORWARD CORNERS-FT CANDLE SEC
0
1000
2000
3000
4000
5000
FLIGHT ALTITUDE IN FEET
1


41° CAMERA CONE ANGLE
2.5 TO 1 RATIO MAX TO MIN SCENE ILLUMINATION
2 TO 1 RATIO MAX TO MIN SCENE ILLUMINATION
.09
.06
.03
3000
4000
5000

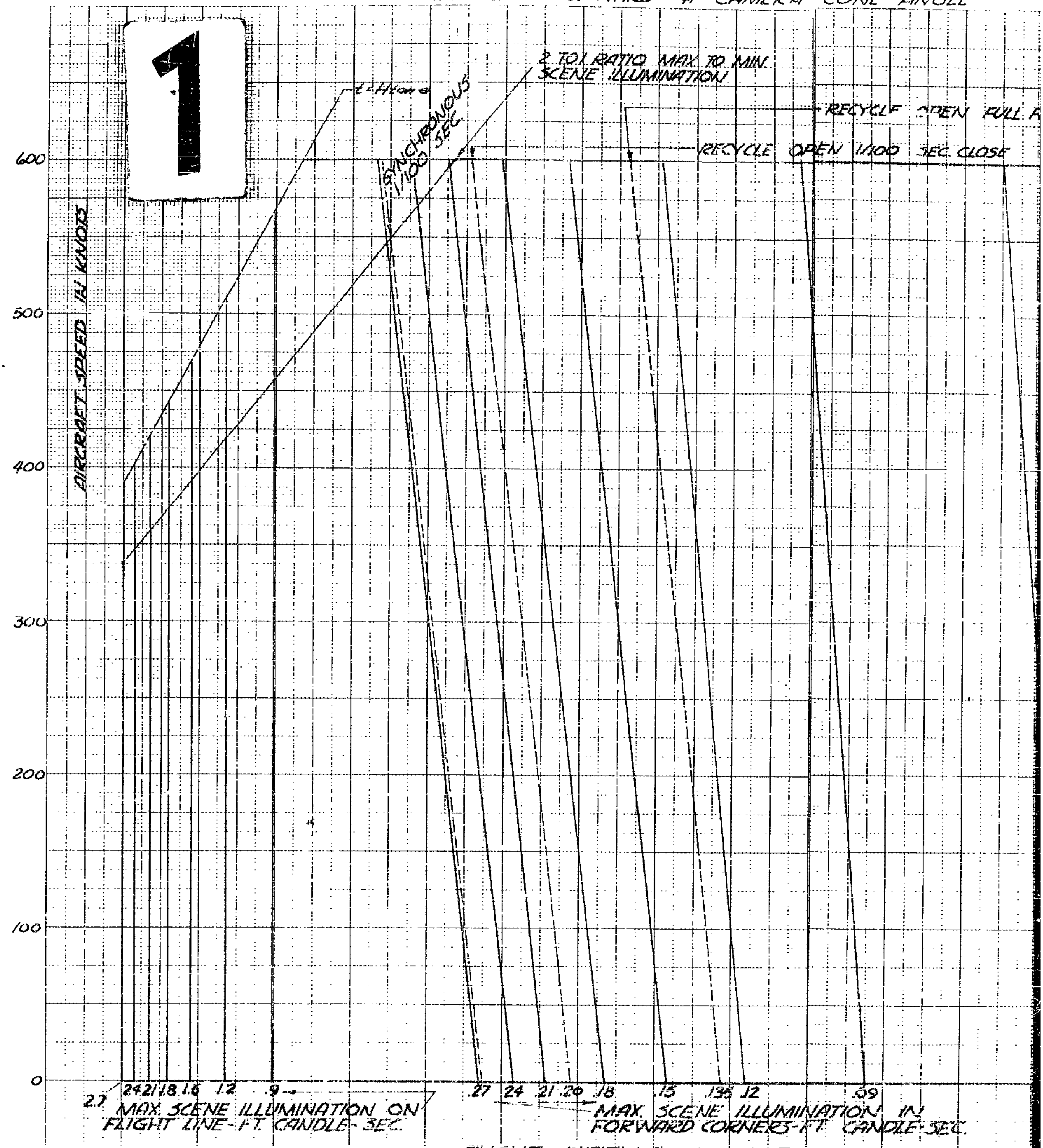


M123 2.5 SEC. DOWNWARD 41° CAMERA CONE
1
3 TO 1 RATIO MAX TO MIN SCENE ILLUMINATION
2.5 TO 1 RATIO MAX TO MIN SCENE ILLUMINATION
SYNCHRONOUS 1/100 SEC.
RECYCLE OPEN 1/100 SEC CLOSE
2 TO 1 RATIO MAX TO MIN SCENE
RECYCLE OPEN FULL
AIRCRAFT SPEED IN KNOTS
600
500
400
300
200
100
27
24
21
18
15
12
9
.27
.24
.21
.20
.18
.15
.135
.12
.09
MAX. SCENE ILLUMINATION ON FLIGHT LINE FT CANDLE SEC
MIN. SCENE ILLUMINATION IN FORWARD CORNERS FT. CANDLE SEC.
FLIGHT ALTITUDE IN FEET
2000
3000
4000
5000
6000

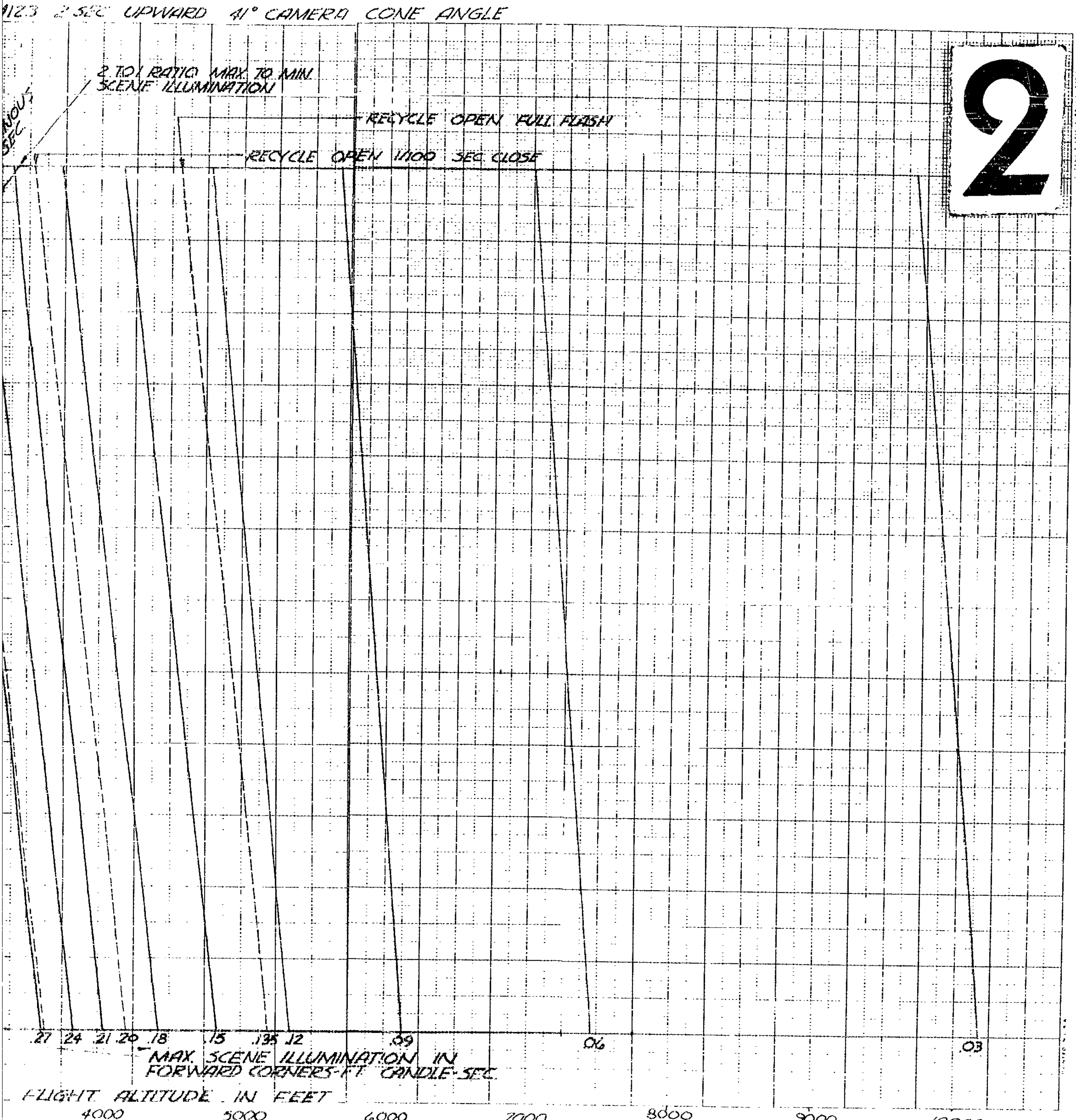


DOWNWARD 41° CAMERA CONE ANGLE
2
MAX TO MIN. SCENE ILLUMINATION
RATIO MAX. TO MIN. SCENE ILLUMINATION
SYNCHRONOUS 1/100 SEC.
RECYCLE OPEN 1/100 SEC CLOSE
2 TO 1 RATIO MAX TO MIN SCENE ILLUMINATION
RECYCLE OPEN FULL FLASH
MIN. AIRCRAFT SPEED FOR 50° OFF OPTICAL AXIS BURST
MIN. AIRCRAFT SPEED FOR 35° OFF OPTICAL AXIS BURST
.18
.15
.135
.12
.09
.06
.03
MIN. SCENE ILLUMINATION IN FORWARD CORNERS-FT. CANDLE-SEC.
FLIGHT ALTITUDE IN FEET
5000
6000
7000
8000
9000
10000

M123 2 SEC UPWARD 41° CAMERA CONE ANGLE

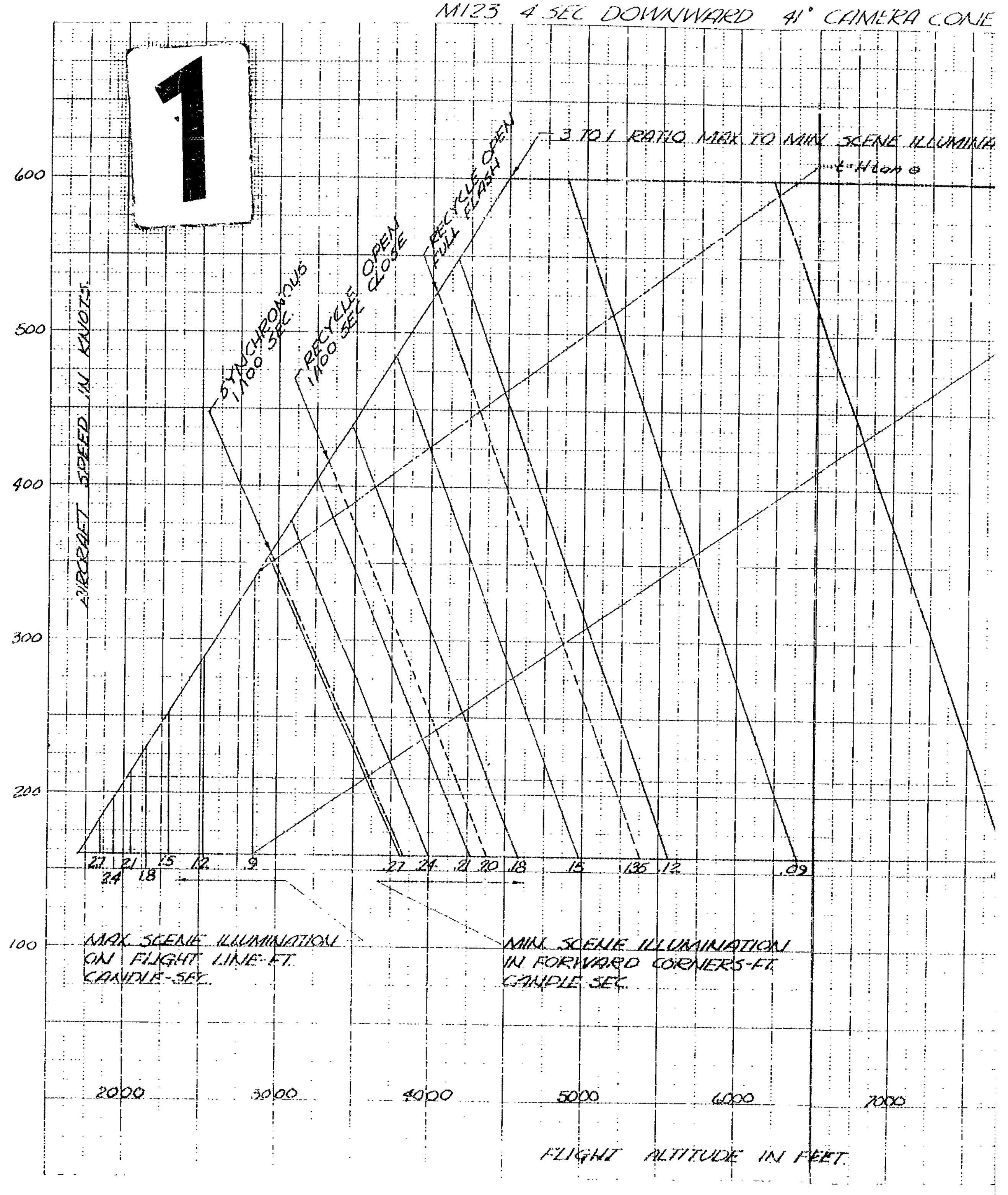


GRAPH NO 6



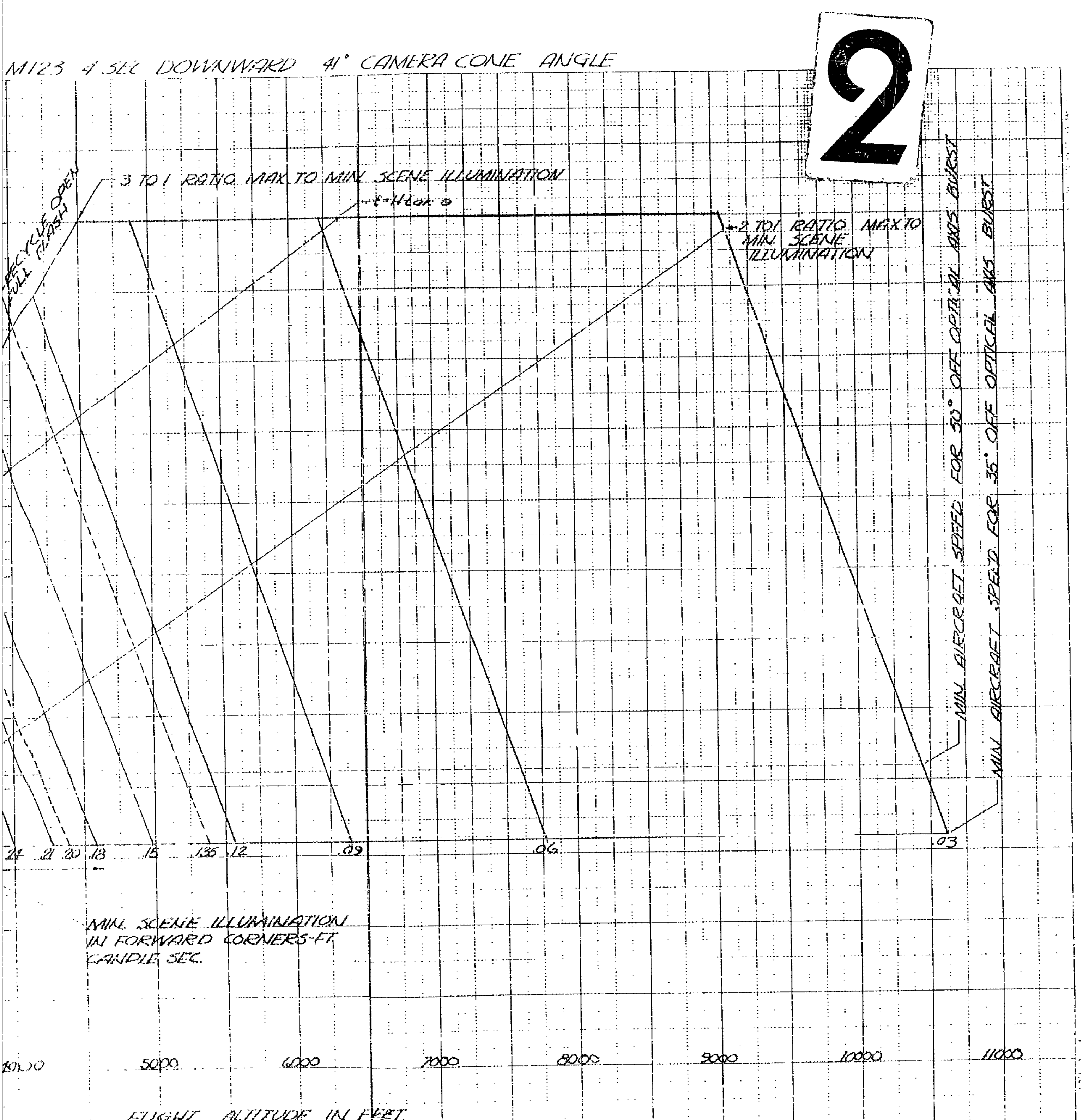
M123 2 SEC UPWARD 41° CAMERA CONE ANGLE
2 TO 1 RATIO MAX TO MIN SCENE ILLUMINATION
RECYCLE OPEN FULL FLASH
RECYCLE OPEN 1/100 SEC CLOSE
.27 .24 .21 .20 .18 .15 .135 .12 .09 .06 .03
MAX. SCENE ILLUMINATION IN FORWARD CORNERS-FT CANDLE-SEC
FLIGHT ALTITUDE IN FEET
4000
5000
6000
7000
8000
9000
10000
2

GRAPH NO. 2

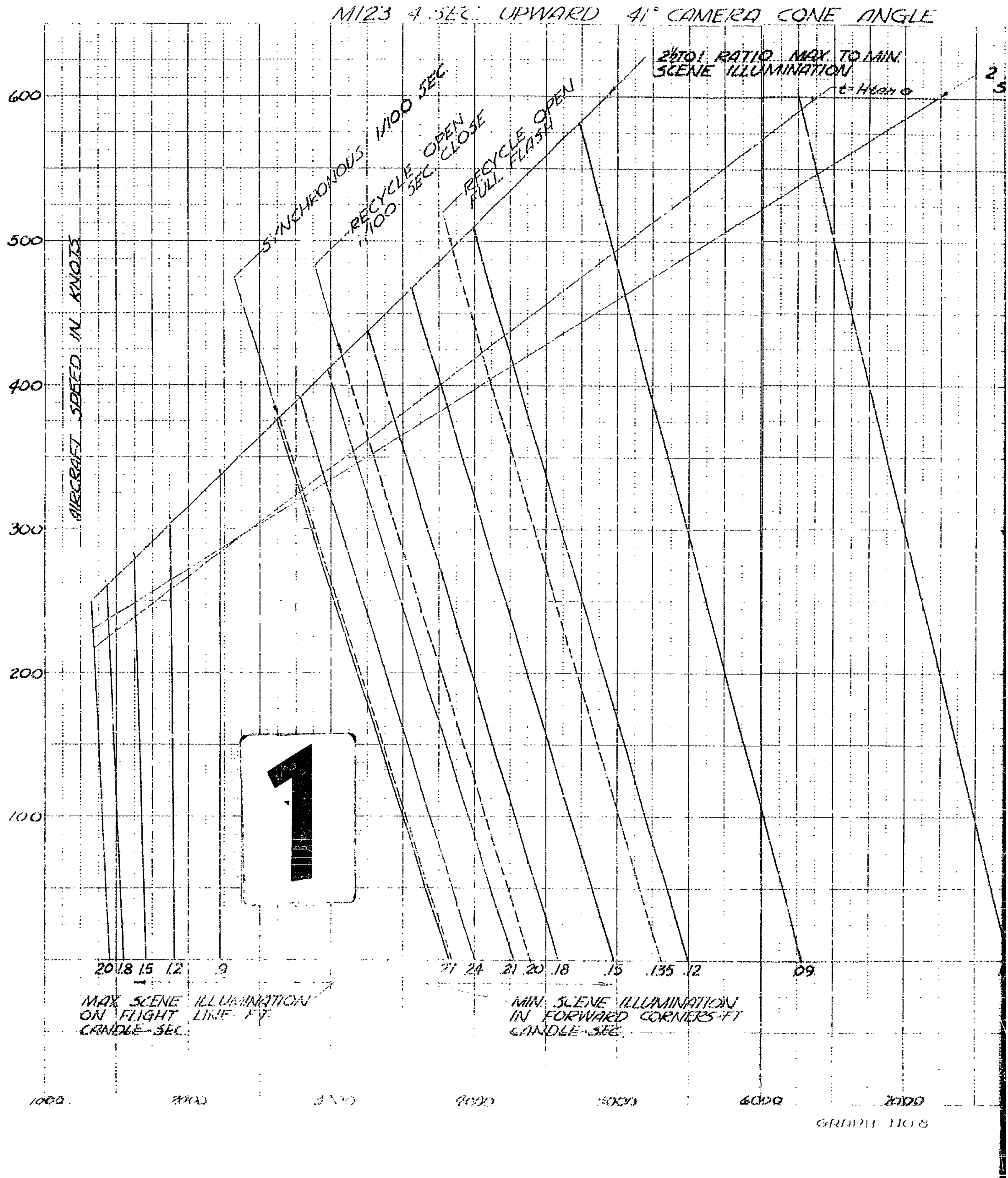

M123 4 SEC DOWNWARD 41° CAMERA CONE
1
3 TO 1 RATIO MAX TO MIN SCENE ILLUMINA
SYNCHRONOUS 1/100 SEC.
RECYCLE OPEN 1/100 SEC CLOSE
RECYCLE OPEN FULL FLASH
AIRCRAFT SPEED IN KNOTS
600
500
400
300
200
100
.27 .24 .21 .18 .15 .12 .9
.27 .24 .21 .20 .18 .15 .135 .12 .09
MAX SCENE ILLUMINATION ON FLIGHT LINE-FT. CANDLE-SEC.
MIN SCENE ILLUMINATION IN FORWARD CORNERS-FT. CANDLE SEC.
2000
3000
4000
5000
6000
7000
FLIGHT ALTITUDE IN FEET

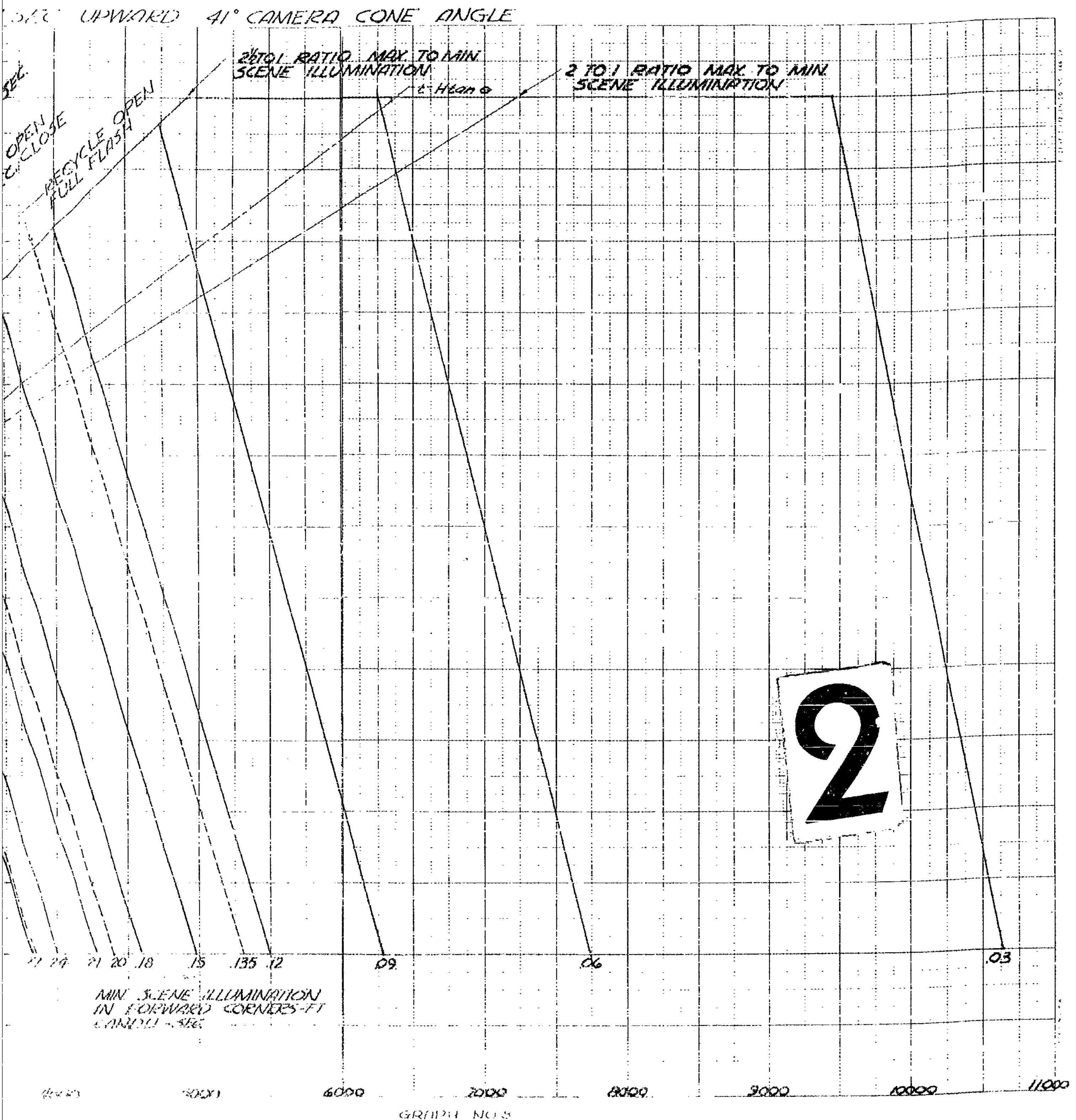
GRAPH NO.7

M123 4 SEC DOWNWARD 41° CAMERA CONE ANGLE



GRAPH NO 7


M123 4 SEC UPWARD 41° CAMERA CONE ANGLE
2½ TO 1 RATIO MAX TO MIN SCENE ILLUMINATION
t=H tan θ
SYNCHRONOUS 1/100 SEC
RECYCLE OPEN 1/100 SEC CLOSE
RECYCLE OPEN FULL FLASH
AIRCRAFT SPEED IN KNOTS
600
500
400
300
200
100
20 1.8 1.5 1.2 .9
.27 .24 .21 .20 .18 .15 .135 .12 .09
MAX SCENE ILLUMINATION ON FLIGHT LINE-FT CANDLE-SEC
MIN SCENE ILLUMINATION IN FORWARD CORNERS-FT CANDLE-SEC
1000
2000
3000
4000
5000
6000
7000
GRAPH NO 8


SEC UPWARD 41° CAMERA CONE ANGLE
2½ TO 1 RATIO MAX TO MIN SCENE ILLUMINATION
2 TO 1 RATIO MAX TO MIN SCENE ILLUMINATION
OPEN
CLOSE
RECYCLE OPEN
FULL FLASH
.20 .18 .15 .135 .12 .09 .06 .03
MIN SCENE ILLUMINATION IN FORWARD CORNERS-FT
6000
7000
8000
9000
10000
11000
2

U. S. NAVAL AIR DEVELOPMENT CENTER, JOHNSVILLE, PENNSYLVANIA
AERONAUTICAL PHOTOGRAPHIC EXPERIMENTAL LABORATORY

Phase Report, Investigation of Current Techniques of Low Altitude Pyrotechnic Flash Night Aerial Photography; by R. Tafel, July 1960, 21p.

This report traces the development of the pyrotechnic flash night photographic system with special emphasis on its application and use in Naval reconnaissance aircraft. A program of mathematical analysis is described which includes the development of a graphical method of presenting the operational limits of the night photographic system. A correlation is made between flight test data and mathematical data which reveals that the widely accepted value of .09 foot-candle-seconds for minimum scene illumination is unrealistically low and that .135 f.c.s. is a more practical value. The advantages of upward cartridge ejection are fully substantiated.

1. Report NADC-AP-6012
2. TED Proj ADC PH-4581

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